AD-A034 498 DEFENSE COMMUNICATIONS ENGINEERING CENTER RESTON VA F/G 17/2
DCS DIGITAL TRANSMISSION SYSTEM PERFORMANCE.(U)
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National Technical Information Service

AD-A034 498

DCS DIGITAL TRANSMISSION SYSTEM PERFORMANCE

Defense Communications Engineering Center
Reston, Virginia

November 1976

ADA034498

021102

TR 12-76

DEFENSE COMMUNICATIONS ENGINEERING CENTER

TECHNICAL REPORT NO. 12-76

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NOVEMBER 1976

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UNCLASSIFIED R220 8 Nov 1976

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR 12-76	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DCS DIGITAL TRANSMISSION SYSTEM PERFORMANCE		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) K. W. Kirk and J. L. Osterholz		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Defense Communications Engineering Center Transmission System Development Branch, R220 1860 Wiehle Avenue, Reston, Virginia 22090		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS Same as 9., above		12. REPORT DATE November 1976
		13. NUMBER OF PAGES 134
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) N/A		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

A. Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

N/A

18. SUPPLEMENTARY NOTES

Review relevance five years from submission date.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Digital Transmission System
DCS Digital System
Terrestrial Digital Transmission
Defense Communications System
Digital Transmission Specifications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report defines suitable circuit and channel performance measures for DCS digital transmission systems. These performance measures are allocated among various segments of a global reference circuit. Relationships are presented which allow basic system design characteristics such as RF link fade margin and individual equipment mean-time-between-outage performance to be chosen that satisfy the selected end-to-end circuit performance measures. A DCS Terrestrial Digital Transmission System Specification is attached as an appendix to this report.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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DCS DIGITAL TRANSMISSION SYSTEM PERFORMANCE

NOVEMBER 1976

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FOREWORD

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ACKNOWLEDGEMENT

The authors wish to express appreciation to Mr. F. R. Wiesman for the significant improvement in consistency of terminology and general readability of this report resulting from his editorial efforts.

SUMMARY

This Technical Report defines performance requirements for the emerging DCS Digital Transmission System. A global circuit model is developed which consists of government-owned terrestrial and satellite segments and a leased terrestrial segment. End-to-end availability and circuit quality requirements are defined and these basic requirements are allocated among the various segments of the circuit. Within each segment, requirements are allocated down to individual line-of-sight or troposcatter links. Link characteristics which are specified include fade margin, system gain, mean-time-between-loss of synchronization and bit count integrity and individual equipment availability.

The global circuit model is defined as consisting of a 2400 mile leased segment in CONUS, two transoceanic satellite hops, and a 2400 mile overseas terrestrial segment. The end-to-end availability requirement for this circuit is specified to be 99%.

The specified measure of voice channel quality is the probability of a transmission disturbance (perceived by the user as a noise burst), during a basic five minute call. The herein specified requirement is that not more than 10% of all calls via the global reference circuit sustain any noticeable disturbance and that not more than 1% of all such calls sustain a disturbance lasting longer than five seconds.

The specified measure of data channel quality is the probability of error-free transmission of 1000 bit data blocks. The specified error-free block requirement is that 99% of all blocks transmitted shall be error-free.

These requirements are translated to link design requirements. The line-of-sight RF link requirement translates to a media unavailability of 3.5×10^{-6}. For a nominal, space-diversity link, this corresponds to a 38 dB margin to the 10^{-4} bit error rate point, but each link margin must be separately chosen based on individual link terrain, climate and diversity characteristics. Appendix C relates these requirements to previously used DCS link design criteria.

For troposcatter links, requirements are stated separately for L-band and C-band. The L-band requirement is the maintenance of at least a 12 dB average signal-to-noise ratio at the demodulator input for all but 0.075 percent of the time. The C-band requirement specifies a 15 dB average signal-to-noise ratio for dual diversity and an 8 dB average signal-to-noise ratio for quad diversity for all but 0.01 percent of the time.

The effects of synchronization loss and loss of bit count integrity are examined. It is concluded that these factors will not cause significant system degradation if not more than 10% of all line-of-sight fade outages and not more than 1% of all troposcatter fade outages result in loss of synchronization or BCI. The resultant requirements for coding protection for the pulse stuffing control word and multiplexer synchronization code protection are derived.

The end-to-end availability requirement of 99% is allocated to individual system elements. This allocation results in a basic RF link equipment unavailability of 4×10^{-5}.

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I. INTRODUCTION

A Digital Transmission System is being developed for the DCS in the post-1980 time frame. A system level specification is needed to describe the required performance of this system. This report describes the system engineering planning leading to a Digital Transmission System Specification and provides supplementary detail relating the System Specification requirements to individual link and equipment design requirements.

The design of the DCS Digital Transmission System was previously addressed in DCEC TR 3-74, "Digital Transmission System Design," March, 1974. TR 3-74 documented key design decisions regarding characteristics of the DCS Digital Transmission System. The current report supplements TR 3-74 by addressing in greater detail the quantitative performance requirements of the system. The following is a summary of the key system design characteristics which are defined by TR 3-74:

- 64 kb/s PCM

  The digital transmission system will use 64 kb/s PCM as its basic clear voice A/D technique implemented in the standard T1 channel grouping.

- 2 b/s/Hz Modulation

  Line of Sight (LOS) link cross-sections of up to 384 channels will be provided using existing frequency allocations--this implies an RF bandwidth occupancy near 2 b/s/Hz.

- Data Interleaving

  Provisions will be made for the selective replacement of individual analog voice channels or combinations of voice channels with digital data streams to provide data transmission service and to provide a means of accommodating digitally submultiplexed secure voice channels.

The Digital Transmission System requirements contained in the System Specification must be based on the satisfaction of DCS end-to-end performance objectives. Current end-to-end circuit quality objectives are specified in the MIL-STD-188 series of standards. Related availability objectives are specified in DCAC 310-130-2. The initial approach to setting Digital Transmission System objectives was thus based on applying the requirements of these documents. These requirements were found to be suitable for specifying the availability and PCM channel transfer characteristics of the new system. In the area of voice circuit noise performance, however, it was found that the current standards inadequately address the "bursty" nature of noise disturbances expected in PCM channels (see Section IV, 2, a, for an elaboration of this issue). For this reason, a new measure of channel noise performance, suitable for use in a digital transmission plant, is developed

herein. This measure is the probability of occurrence of a fade outage during a basic five minute call. The details of the derivation of this measure are discussed in Section IV,2,a. It is envisioned that this measure will become the standard circuit quality requirement for digital transmission of voice and will ultimately be added to MIL-STD-188-100.

The allocation of end-to-end requirements discussed above to individual links and equipment demands an allocation model. This model should describe the composition of the end-to-end circuit in terms of its constituent elements. Such a model is currently contained in MIL-STD-188-100 which describes a 12,000 mile (19,308 km) reference circuit. This reference circuit is a series combination of various numbers of voice bandwidth links (a voice bandwidth link being defined as the span between successive VF breakouts on the circuit in question). This reference model was initially considered for use herein but it was found that it inadequately describes the expected post-1980 DCS for several reasons. The most important reason is the emergence of satellite channels as the dominant, transoceanic transmission medium for the DCS. Satellite transmission contributes to the overall performance of DCS circuits in a way that is independent of distance. Both the availability and the channel quality of circuits which are, in part, derived from a satellite relay are not well described by a model such as the current MIL-STD-188 model which uses distance as its major allocation parameter.

A second important reason for modifying the MIL-STD-188 model is the difference in the way noise accumulates on PCM channels as compared to FDM channels. In FDM channels, the major sources of noise are media noise and intermodulation noise which accumulate, more or less, on a mileage basis. In PCM, the major source of channel noise, except in the noise bursts discussed earlier, is PCM A/D conversion noise which occurs only when the basic PCM channel bank is traversed. The proposed new reference channel attempts to realistically reflect the expected distribution of PCM A/D conversions.

A third reason for modifying the reference circuit model is to explicitly reflect a relative mix of line-of-sight and tropospheric scatter transmission. This mix is of interest because the PCM burst noise of these two transmission media is noticeably different.

The proposed new reference circuit is discussed in Section II, 1. It is clear that any set of assumptions for the composition of a standard reference circuit are a compromise since the standard reference circuit attempts, in a single model, to be suitably representative of the variety of actual circuits in the current and future DCS. The primary use of the standard reference circuit is as a basis for an allocation model. This allocation determines the requirements for individual link and equipment parameters in order to meet DCS end-to-end goals. Clearly, when the system is built using these allocated values, if the reference circuit were too pessimistic, the actual system will be overdesigned and will, on the average, provide performance better than the original goals, presumably at greater than

necessary cost. Conversely, if the model is too optimistic, underdesign will result and the actual system will provide substandard performance. Effort is currently underway at DCEC to construct a computer model of DCS connectivity in a way that will allow an evaluation of the actual distribution of system performance. This model, when available, will supplement the standard reference circuit concept as an allocation tool. In such a computer model, the standard reference circuit should be significantly more pessimistic than the average circuit but less pessimistic than the worst case circuit. The currently proposed reference reflects engineering judgment as to the composition of a "moderately worst case" connectivity.

II. RELATIONSHIP OF THE DIGITAL TRANSMISSION SYSTEM TO OVERALL TRANSMISSION REQUIREMENTS

1. GLOBAL REFERENCE CIRCUIT

The Digital Transmission System is being implemented in a series of separate but related projects which will eventually replace most of the existing analog DCS. The selection of locations for the individual projects is determined by geopolitical considerations, and by other factors. The rate at which these projects are implemented, and hence the rate of digital conversion of the DCS, is governed by annual funding limitations. Thus, the terrestrial digital transmission plant must be designed to interoperate with a variable mix of analog and digital facilities at various stages of the conversion. In parallel with the conversion of the terrestrial plant to digital operations, the Defense Satellite Communications System (DSCS) is being converted to digital operation with parameters similar to those of the terrestrial plant.

Quantitative requirements for the Digital Transmission System are based on an allocation of the end-to-end requirements of a global reference circuit. The global reference circuit proposed herein consists of four segments: a leased, common carrier segment of 2400 mile (3862 km) length spanning CONUS; two satellite segments of one hop each; and an overseas terrestrial segment of government-owned microwave and troposcatter facilities 2400 miles (3862 km) in length. This global reference circuit is defined by its configuration rather than by a specified length because the performance of the satellite hops is independent of their length. It is roughly equivalent to the current 12,000 mile (19,308 km) reference circuit in that it reflects a relatively worst-case global connectivity. The 2400 mile (3862 km) CONUS segment is of sufficient length to span the continent from coast to coast and the 2400 mile (3862 km) overseas terrestrial segment reflects a nearly worst-case length since such a span would extend, for example, from Scotland to Turkey in Europe or from the Phillipines to Japan in the Far East.

In addition to circuit length, the reference circuit must define the relative mix of facilities to be used in the terrestrial segments (i.e., line-of-sight, troposcatter, cable) and the multiplexing composition of the circuit (i.e., relative percentage of stations that are baseband repeaters, or provide through-group connection or VF channel breakout for this particular circuit). Based on studies of representative regions of the existing overseas DCS, 70% of the overseas terrestrial route mileage was allocated to line-of-sight transmission and 30% was allocated to tropospheric scatter. (This mix can vary considerably depending upon locale, but the variation would not be greater than to approximately

double or half the total number of troposcatter route miles in the circuit with a corresponding ± 50% variation in line-of-sight route mileage. It will be shown later that this degree of variation has relatively modest impact on detailed link and equipment requirements allocations.)

The multiplex composition of the reference circuit is based on studies of the current DCS. VF interconnection is used at both ends of each satellite hop in accordance with the current DSCS configuration. Studies of the composition of the current DCS overseas plant indicate that the majority of circuits are composed of 4 or less tandem channels (i.e., three or less VF interconnects). Since the 2400-mile (3862 km) terrestrial segment is considerably longer than the average circuit, it is composed of four tandem VF channels, each of 600-mile (965 km) length. Throughout the DCS, a typical distance between FDM group multiplexers is three RF links. It is assumed that this spacing will also be typical for the spacing of Level 2 Time Division Multiplexers. (This spacing is lower in dense areas such as central Germany where multiplex breakout occurs at nearly every site and it is higher in interregional connecting routes where moderately long strings of repeaters are encountered.) Thus, the overseas terrestrial reference segment contains a through-group connection every three RF links with the intervening stations being baseband repeaters.

A troposcatter link length of 180 statute miles (290 km) and a line-of-sight length of 30 statute miles (48 km) were chosen as a representative. Thus, for a 600-mile channel, a ratio of 14 line-of-sight links to one troposcatter link in tandem results in the appropriate relative mix of line-of-sight and troposcatter links.

A 600-mile (965 km) channel (one of the four channels comprising the reference segment) is defined as a DCS reference channel. The DCS reference channel, which is shown in Figure 1, illustrates the two parameters above, i.e., the 14 to 1 ratio of line-of-sight links to troposcatter links, and the through-group connection every three RF links with the intervening stations being unattended baseband repeaters.

2. UNAVAILABILITY ALLOCATION

Unavailability is a basic measurement of the performance of a communications channel. System unavailability requirements are established herein and these requirements are allocated among various segments of the reference circuit. Unavailability, as discussed herein, is defined as any loss of continuity or excessive channel degradation which occurs for a period in excess of one minute. Disturbances with durations shorter than one minute are covered by a channel quality measure discussed in Section II, 3.

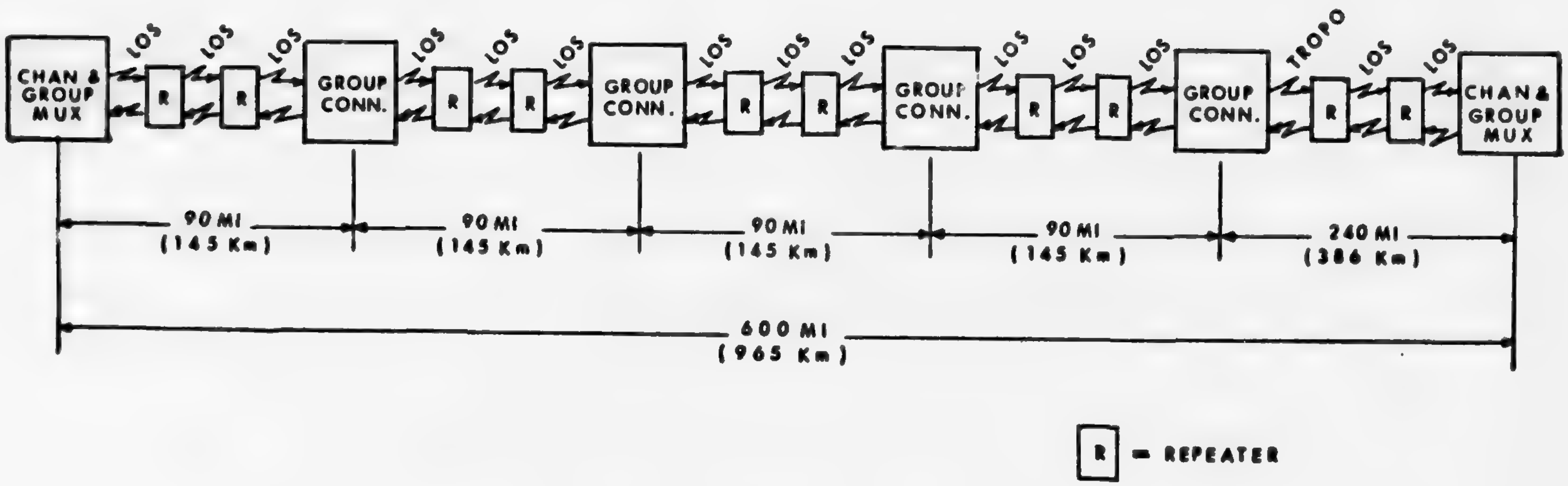


FIGURE 1. DCS REFERENCE CHANNEL

An allocation of unavailability among the various segments of the reference circuit has been developed based on the following assumptions:

- The major determinant of unavailability will be equipment failures, hence allocations should reflect the relative quantity and complexity of equipment in each segment.

- Common carrier (leased) and DCS terrestrial transmission facilities should have approximately equal allocations because of similar distances (hence approximately equal total quantity of equipment traversed and similar hardware complexity). (This is probably a good assumption when comparing CONUS leased with DCS owned facilities but is not necessarily true for overseas leases. U.S. decisions to lease versus providing U.S. owned facilities overseas are affected by many factors only one of which is the expected availability of the channel. The impact of the assumption of equivalence between the availability of government owned and overseas leased facilities, as used herein, is to decide not to overdesign the U.S. owned portions of the system to attempt to compensate for severely substandard leased facilities.)

- The satellite segment has far fewer equipments than the terrestrial segment (2 earth terminals and 1 space repeater versus 60 terrestrial terminals) and should thus have a lower overall allocation. The relative unavailability allocations between satellite and terrestrial segments should not be directly proportional to terminal count, however, due to the greater complexity of the satellite earth terminals, and to the long outage time allocation (and hence large impact on availability) that must be planned for space repeater outages, even with an adequate replenishment program. A relative unavailability allocation ratio of 4 to 1 between the terrestrial segment and the satellite segment has been chosen as a compromise between these factors.

Based on these assumptions, and an end-to-end availability requirement of 99% (an allowable unavailability of not more than 1%), the following unavailability allocation to the various circuit segments has been made:

CONUS common carrier segments	$4 \cdot 10^{-3}$
Satellite transoceanic segment #1	10^{-3}
Satellite transoceanic segment #2	10^{-3}
Overseas terrestrial segment	$4 \cdot 10^{-3}$
TOTAL:	10^{-2}

(This allocation is based on dedicated circuit requirements. For switched circuits, assuming dual routing between switches, transmission unavailability becomes much less important than switch blocking probability. A significant

outage in the transmission plant significantly affects blocking probability for low priority calls, with lesser effect as priority increases. A treatment of the interrelationship of transmission unavailability to switched service unavailability is beyond the scope of this report and can be avoided herein since the dedicated circuit is expected to exert the most stringent requirement on transmission plant availability.)

Section IV, 3, c, of this report discusses how the basic unavailability allocation to the overseas terrestrial segment ($4 \cdot 10^{-3}$) is further allocated to its constituent elements.

3. CIRCUIT QUALITY

The transmission quality of digitally derived voice circuits is primarily determined by the characteristics of the voice A/D process, the number of tandem A/D conversions traversed by the circuit, and the characteristics of transmission error occurrences. Regarding the first determinant of circuit quality, the A/D process, previous studies led to the choice of 64 Kb/s PCM for the basic voice A/D process, in consonance with commercial standards. As was reported in the previous report, TR 3-74, the transfer response and noise quality of each individual channel thus derived exceeds the quality of the analog channel being replaced. Thus, in the absence of transmission errors, digital channels will provide quality greater than existing analog channels and in excess of MIL-STD-188-100 requirements. (An exception to the MIL-STD-188-100 requirements is in the area of envelope delay distortion in which commercial PCM standards are somewhat lower than the MIL-STD-188-100 requirements. This will not be of great concern in the near term due to the general use of modems with automatic equalization and for the fully digital system due to direct data transmission without the need for modems.) Since the envisioned digital multiplex equipment provides superior channel quality, no detailed allocation of circuit characteristics associated with the voice A/D process is considered necessary.

Regarding the second determinant of circuit quality, the number of tandem A/D conversions in a circuit, the MIL-STD-188-100 standard reference circuit envisions up to 12 tandem channels. Since, as previously discussed, each A/D conversion results in channel quality exceeding the MIL-STD-188-100 requirements, tandem voice A/D conversions in excess of 12 are tolerable within the intent of the 12,000 mile (19,308 km) reference circuits of MIL-STD-188-100. In fact, the composition of the global reference circuit described herein contains only five tandem A/D conversions for the entire transoceanic and terrestrial overseas segments. Thus tandeming of A/D conversions is not expected to be a problem.

Regarding the third determinant of circuit quality, the effects of transmission errors on digital data and PCM encoded voice, two new quality parameters have been developed which are an improved description of the effect of errors on circuit quality. A frequently used previous measure of the effect of errors was average bit error rate. This measure is

appropriate if transmission errors are spread more or less uniformly throughout the received bit stream and if their interarrival interval is short enough so that more than one error can affect an average message. Such is frequently the case in data transmission via voice frequency modems or via digital satellite channels. The line-of-sight and troposcatter links which make up the terrestrial DCS do not behave in this way. For these links, errors are mainly caused by fades and thus occur in bursts. These bursts are very poorly described by average bit error rate. It is expected that the average bit error rate on a typical 600-mile terrestrial channel will be on the order of 10^{-8} or an average time between individual bit errors on a typical 64 Kb/s channel of about 1/2 hour. This is clearly a meaningless measure since the errors will actually occur in bursts, with the bursts separated by considerably more than 1/2 hour.

A more usable measure than average bit error rate is the probability that the bit error rate is above some threshold value. Such a measure is much more usable on a burst channel than average bit error rate since it describes the channel in terms of the percentage of usable vs. nonusable time, i.e., the cumulative percentage of time spent in error bursts. Unfortunately, this measure is still deficient in that it tells nothing about the temporal distribution of bursts. One cannot determine from such a cumulative measure whether each telephone call will be disturbed by a short error burst or whether only an occasional call will be disturbed by a much longer burst.

Two new measures of channel quality have been developed which supplement cumulative measures by describing the expected duration and expected interval between error bursts. One of these measures describes voice circuit quality in terms of the probability that any voice call will be disturbed by an error burst and by the expected duration of the burst. The other measure describes data circuit performance in terms of the probability of error-free transmission of data blocks. The details of the development of these measures are contained in Section IV,2,a, and IV,2,b. Section IV,3,a, allocates these requirements to the constituent elements of the DCS. Section IV,3,d, through IV,3,i, discuss the relationship between these channel quality requirements and individual RF link parameters, such as fade margin.

III. SYSTEM TRANSITION CONSIDERATIONS

Upon initial implementation of digital transmission segments, the DCS will primarily consist of analog VF channels. Data transmission through the system at rates below 9.6 kb/s will be accomplished using modems via analog VF channels. A 50 kb/s direct digital transmission capability will also exist for secure voice requirements. During the early 1980's, the AN/TTC-39 switch is scheduled for DCS deployment and the 16 kb/s AUTOSEVOCOM II System is scheduled for implementation. At that time, a basic additional requirement will be imposed on the digital transmission system; that of network synchronization. This requirement will be imposed because an AUTOSEVOCOM II connection requires simultaneous bit-rate synchronization of both subscribers, of their serving digital switches, and of all digital multiplexers traversed.

This synchronous requirement imposes a need for station master clocks in all digital transmission nodes and the ability for these clocks to control the bit-rate timing of all switches and multiplexers in the node. It must be possible to closely synchronize all station clocks within the network, and sufficient buffering must be provided on each link to accommodate short-term variations between the incoming bit-rate and the station clock rate. Several techniques are currently under investigation to accomplish the synchronization function. Each of these techniques will provide adequate network synchronization but they differ as to their survivability, maintainability, and other operational characteristics. A selection of the specific synchronization technique to be used in the DCS is expected during CY 1977. In the meantime, digital transmission equipments should contain provisions to interface with a station clock system at their characteristic bit-rate. Suitable equipment to perform the station clock synchronization function and the required link buffering will be defined when the synchronization technique is selected.

After system conversion to a synchronous mode of network timing, it is intended to eliminate all unnecessary pulse stuffing multiplexer operations. This pulse stuffing in the Level 2 TDM multiplexer is necessary until synchronous mode conversion occurs to allow through-group connection of unsynchronized groups. Transmission errors in pulse-stuffing control words are a potential source of loss of bit-count integrity (BCI) which need not be tolerated in a synchronous network. To this end, Level 2 TDM multiplexers should be capable of both synchronous and asynchronous operation.

Another transition consideration relates to the digital transmission equipments installed in Europe during the earliest stages of digitization (FKV and DEB Stage 1). These installations do not fully meet all requirements of the System Specification. In some cases, permanent deviations from the System Specification may be acceptable for these few equipments. In other cases, such as the case of synchronous mode operation, an improvement in these initial equipments will be required. The specific plan for any necessary modification to the initial FKV and DEB Stage 1 installations will be the subject of a separate report.

As digital transmission capability becomes more widespread, digital submultiplexing will become a practical means of transmitting digital data through the system. The major factor which affects the advisability of converting existing medium speed data (up to 9.6 kb/s) and VFCT traffic to digital submultiplexing is the percentage of the network that has been converted to digital transmission and hence the percentage of data channels which can be transmitted from end-to-end in digital form without the need for intermediate conversion back to analog to transit not yet converted analog regions. The usefulness of digital submultiplexing will be regularly reviewed throughout the digital portion of the network and submultiplexers will be applied where appropriate cross-sections of data channels exist which can be served on an end-to-end digital basis. It is planned to introduce submultiplexed data streams into the system by the selective replacement of one or more individual voice channels in the Level-1 PCM multiplexer with digital data streams at 64 kb/s, or multiples thereof. This mode of operation is known as data interleaving since the data bits are interleaved with PCM bits in the combined output bit stream of the multiplexer. The planned data interleaving options are listed in Table 1.

TABLE 1. DATA INTERLEAVING OPTIONS

Bit Rate (kb/s)	VF Channels Replaced	Data Source
56/64	1	Level A TDM Submultiplexers
128	2	Level A TDM Submultiplexers
256	4	Level A TDM Submultiplexers or non-DCS CVSD Multiplexers
512	8	Level A TDM Submultiplexers or non-DCS CVSD Multiplexers
50	1	KY-3 or Related Secure Voice Equipments
0-20	1	Miscellaneous

The 56 kb/s data interleaving rate listed above is intended to allow tandem connection of appropriate submultiplexer and data interleaving channels with the common carrier digital service offering at 56 kb/s.

As the digital data load of the DCS increases, progressively more channel replacement for data interleaving will occur up to a maximum of about half of the channels in any Level 1 PCM multiplexer. If the data load increases beyond this point, it is planned to use the Transitional Multiplexer described in TR 3-74, or combinations of Digital Group Multiplex equipment under development by TRI-TAC, to accommodate these cross-sections.

IV. QUANTITATIVE SPECIFICATION REQUIREMENTS

1. GENERAL

The System Specification contains quantitative performance requirements for various elements of the Terrestrial Digital Transmission System. These requirements, specified at the system level, result in imposing detailed requirements on specific equipment and on the design of RF links. It is a major function of this report to discuss the rationale for selection of the quantitative values contained in the System Specification and to show how these values relate to, and should be used for, the selection of detailed equipment and link design requirements.

The performance of the system is prescribed in the System Specification by two basic requirements. The first prescribes the quality of channels to be provided by the system, assuming that the channels are available. The second requirement prescribes the availability of the channels. Appropriate requirements of both types, quality and availability, are applied at each major level of the system, i.e., individual RF link, digroup, and channel.

The basic quality measure for a digital transmission system is its error performance. Several different measures of error performance are applied, each of which is meaningful to a particular type of user. The following section describes considerations relating to the selection of appropriate channel quality measures. Following that is a discussion of each specific quantitative requirement.

2. RATIONALE FOR ERROR PARAMETER SELECTION

a. Error Performance Measures. The primary measure of transmission quality for a digital system is its error performance. This is particularly true for a system which regenerates the digital signal at each repeater since errors, rather than distortion, will accumulate through tandem sections of the system. Therefore, an appropriate structure for specifying system error performance is first defined, then the requirement for other, related parameters is discussed.

Transmission errors will occur in the digital transmission system in two distinctly different modes. One mode is a relatively constant, long-term error rate which will occur due to equipment degradation (as opposed to failure), due to interference and due to long-term power fading on satellite hops. An error rate of 10^{-6} is specified as the acceptable threshold for steady-state error rate conditions. This error rate is at least one order of magnitude more stringent than the level at which significant user disturbance occurs. A circuit is considered unavailable when its steady-state error rate is greater than 10^{-6}.

The other system error mode results from multipath propagation disturbances on line-of-sight and troposcatter links. For these disturbances, a dynamic measure of error performance is needed. Multipath fading occurs with such rapid variation that the error performance changes too quickly to be characterized by a "rate". In addition, isolated single bit errors are of little importance since, in the transmission of digitized voice via PCM, the occurrence of a single, isolated bit error will be hardly noticed by the user. Similarly, for most modern data transmission systems which use either ARQ or forward error correction for error control, a single bit error is of little consequence. It is the temporal relationship between errors, i.e., whether they are grouped together in time so that they reinforce each other's disturbing effect, that is the important measure of a communications channel.

For both line-of-sight channels and troposcatter channels as they are expected to be implemented in the DCS (dual diversity line-of-sight links with 30-40 dB fade margin, and quad diversity troposcatter links engineered for 95% service probability), the error performance of the channel will be characterized by relatively long periods with no errors interspersed with considerably shorter periods of deep fade in which a number of errors are grouped closely enough together to constitute an essentially continuous interruption to the usability of the channel. The transition of the channel from the error-free state to the severely disturbed state is quite rapid. User perception of 64 kb/s PCM channel quality changes dramatically with a two order-of-magnitude change in error rate from around $3 \cdot 10^{-6}$ (one error every 5 seconds) to $3 \cdot 10^{-4}$ (20 errors per second). In this vicinity of error rate, a two order-of-magnitude change results from about a 2 dB change in received signal level. During deep multipath fades, the received signal level may be expected to change by tens of dB per second. Thus, if the channel, as perceived by the user, transitions from good to bad in a 2 dB range of signal level, this transition will occur in several hundred milliseconds. The mean fade duration on line-of-sight links will be on the order of five seconds. Since the transition period from a good channel to a severely disturbed one is so short relative to the fade duration, such fades can be described by only their duration, assuming essentially complete unacceptability from the onset of the fade to its end. It remains necessary only to choose an appropriate threshold at which to measure the beginning and ending of a fade outage to complete the outage characterization.

If a 64 kb/s PCM channel is observed during a multipath fade, the fade will have reached considerable depth before the first error is observed on the channel. In a system with a 30-35 dB fade margin, the signal will have faded more than 30 dB before this error occurs. Due to the rapid onset of errors in a fading channel, the received signal level at which the first error is expected to occur is a reasonable threshold for determining the duration of the fade. This signal level will not be the same

for each fade, since error occurrences are a probabilistic phenomenon, but a signal level can be defined which represents the mean value of the signal level at which the onset of errors is expected. The signal level of this mean value is a function of fade rate. The more rapidly the signal level fades, the lower will be the point at which the onset of errors occur. For a typical fade rate of 10 dB/second, the mean signal level of error onset is approximately the level corresponding to a 10^{-4} bit error probability. This is an appropriate threshold signal level for the range of fade rates expected to occur on line-of-sight links. For troposcatter, a slightly lower bit error probability would be appropriate but the value of 10^{-4} is selected as a conservative value to be used for both line-of-sight and troposcatter channels.

Having defined a threshold above which the channel is considered to be unperturbed, and below which the channel is considered to be unacceptable, a fade outage is defined as the event that begins when the highest signal level on any diversity branch of a link falls below the specified threshold, and ends when the highest signal level on any diversity branch has again risen through the threshold value.

The characteristics of fade outages have been examined for typical line-of-sight and troposcatter channels. It has been found that the line-of-sight channel is characterized by very infrequent fades of approximately 4 seconds mean duration, whereas the troposcatter channel is characterized by more frequent fades with mean duration in the 50-500 millisecond range (the actual troposcatter mean duration depends on the path and the operating frequency). A channel which traverses both line-of-sight and troposcatter RF links will therefore experience two distinctly different types of fade outage duration with markedly different interference potential.

A user will be affected differently by different types of outages. Three broad categories of voice user reaction to fade outages are postulated. (Data user reaction is more usefully described by the affect of the outages on error-free throughput which is a direct function of the percentage of error-free data blocks). The first broad category occurs when a voice user is subjected to an isolated fade outage of very short duration, e.g., less than 200 milliseconds. His reaction will be to barely notice the disturbance. This will be true even for repeated but suitably infrequent outages of such short duration. The second broad category occurs over some range of longer fade duration, e.g., 1/5 second to 5 seconds. The user will experience significant annoyance but will continue to communicate when the outage is over. Similarly, for some recurrent rate of short duration outages, i.e., 2 to 4 outages per minute, none of which is greater than 200 milliseconds in duration, annoyance rather than total disruption will occur. (This type of recurrent disturbance is typical of a troposcatter channel during long term fading and thus will afflict the user with a relatively long period of disturbed performance whereas the 1/2 to 5 second line-of-sight fade will

normally be an isolated event). Finally, the third broad category occurs when the outage exceeds some duration such that calls are abandoned due to lack of patience. Outages of any noticeable duration will be disturbing to the user and their probability of occurrence should be controlled. Outages which are long enough to cause call abandonment are a much more severe disturbance than outages for which calls are not abandoned. Thus, the probability of occurrence of these longer outages should be substantially less than the probability of occurrence of shorter outages. The determination of an appropriate outage duration threshold above which call abandonment is expected can best be determined by subjective user preference testing. In the absence of such tests, a five-second duration has been chosen as a conservative value. That is, it is assumed that calls subjected to outages shorter than five seconds will be held and those with outages longer than five seconds will be abandoned.

In view of the above considerations, five ranges of outage are defined as follows:

- Range I. Outages under 200 milliseconds duration which are significantly separated in time from any other outage. Such outages will normally occur on a troposcatter link operating with adequate margin. The allowable probability of occurrence of these outages need not be specified since their effect on the user is trivial.

- Range II. Outages with durations in the range from 200 milliseconds to five seconds which are significantly separated in time from any other outage. Such outages may occur on either a line-of-sight or a troposcatter link operating with adequate margin (or less than adequate margin if the frequency of occurrence is high). The allowable probability of occurrence of such an outage should be specified with a value based on its annoyance to the user.

- Range III. Outages with durations greater than 5 seconds but less than 2 minutes. Such outages will normally occur on a line-of-sight link. The allowable probability of occurrences of such outages should be specified with a requirement more stringent than that for Range II since such an outage is considered to be a disruption to the user which would cause call termination.

- Range IV. A recurrent set of outages of average duration under 200 milliseconds which occurs at an average rate of from 2 to 5 per minute. This condition will normally occur on a troposcatter channel operating with barely adequate margin. The allowable probability of existence of such a condition should be specified with a value based on its annoyance to the user.

- Range V. Outages with duration greater than 2 minutes or recurrent outages of any duration which occur more frequently than 5 per minute. The duration of any such outages or period of recurrent outages should be included in the total unavailability specification since the channel is considered essentially unusable. The outages described by this range will normally occur on a troposcatter channel with long-term fading in excess of the fade margin, or on a line-of-sight channel experiencing anomalous index of refraction conditions.

In summary, it is proposed that the basic performance parameter of channels in the digital transmission system be two sets of specifications: one for channels utilized for voice that describes the probability of occurrence of temporally grouped errors where such an error grouping is called a 'fade outage'; and one for channels utilized for data that describes the probability of error-free transmission of blocks of data of specified length. A fade outage is defined in terms of an RF link signal strength threshold corresponding to a 10^{-4} bit-error probability. Five ranges of fade outage conditions are defined, one of which is considered to be negligible (Range I), one of which is of sufficient duration to be included in the unavailability specification (Range V) and three (Ranges II, III and IV) which are proposed to be controlled by separate probability of occurrence specifications which consider the disturbing effect of the specific outage ranges addressed. These measures of channel quality have the considerable advantage over either average bit error rate or availability in that they actually reflect the types of fading phenomena which occur. Numerical values for these requirements will be derived in Section IV,3,a.

b. Error-Free Data Blocks. Most data transmission systems separate the data to be transmitted into blocks for error control purposes. A parameter of interest to the data user is the percentage of such blocks which are transmitted with no errors. In a system using ARQ error control techniques, all blocks which are not error-free must be retransmitted. In a system using error correction coding, a small number of errors can be corrected, but blocks with a large number of errors must be retransmitted. The performance of data transmission channels is described by the probability of fade outage requirements described in the preceding section, supplemented by an error-free block requirement. Between them they describe the incidence of outages where a number of adjacent blocks are affected by errors and the total percentage of data blocks which contain errors, although most of the affected blocks will lie within the time boundaries of the fades described by the probability of fade outage specification.

All data transmission systems do not use the same block length, but a representative block length must be chosen for specification purposes. A 1000 bit data block has been chosen. A method is discussed in Section IV,3,f for extrapolating from the specified performance for a 1000 bit data block to any other length.

Most data transmission channels can be characterized by describing the probability that undetected transmission errors will occur and by the throughput efficiency of the channel. Stringent requirements for undetected error probability are met by using error detecting or error correcting coding techniques. Such techniques reduce the channel efficiency in return for error protection. For channels in which the errors occur in long bursts, such as the terrestrial channels discussed herein, error correcting codes have not been an attractive error control technique. Instead, error detection coding and ARQ are normally used. Thus, the specified requirement for error-free data blocks is based on meeting the efficiency requirement of a channel with ARQ error control. (Efficiency is equal to the percentage of transmitted data blocks which are received error-free.)

The normally accepted requirement for channel efficiency for data services such as AUTODIN is .99 (but this value is not particularly critical since load variations or equipment failures, rather than error-caused transmission inefficiency, dominate both data system sizing and transmission delay). In order to meet this requirement, an end-to-end error-free block requirement of 0.99 is specified. This requirement is allocated equally among the CONUS, transoceanic and overseas segments of the global reference circuit. Thus, the requirement of each segment for error-free data blocks is 0.9975. The overseas terrestrial requirement is further allocated to component channels on a mileage basis. Thus, the requirement for a 600-mile (965 km) reference channel is 0.99937, the requirement for a line-of-sight link is 0.99997, and the requirement for a troposcatter link is 0.99978.

3. DERIVATION OF DETAILED REQUIREMENTS

a. Probability of Fade Outage. A system requirement for probability of fade outage will now be derived based on the DCS global reference circuit described in Section II. The requirement value will be selected on an end-to-end basis and then allocated to individual constituent sections of the end-to-end circuit and to individual RF links.

The requirements for probability of fade outage in Ranges II and III (as defined in IV, 2,a) will be specified on a per-call-minute basis since the probability of occurrence during a call of the fades described by these ranges is approximately proportional to holding time (see Appendix B). Thus the fade outage probability on a typical five-minute call is approximately five times the specified probability per-call-minute. The requirement for probability of fade outage in Range IV will be specified on a cumulative probability basis since this range of outage describes a long-term condition rather than a single discrete event. The requirement for probability of outage in Range V is discussed in Section IV, 3,c under availability.

The requirements for probability of occurrence of Range II, III, and IV outages are proposed as follows:

(a) The probability of occurrence of a fade outage whose duration is greater than 200 milliseconds but less than 5 seconds shall not exceed 0.02 per-call-minute.

(b) The probability of occurrence of a fade outage whose duration is greater than 5 seconds but less than 1 minute shall not exceed 0.002 per-call-minute.

(c) The probability that a condition exists in which recurrent outages of less than 200 milliseconds' duration occur at a rate in the range of 2 to 5 per minute shall not exceed 0.01.

Since it has been assumed that outage probability on a call is proportional to call holding time, the combined impact of these requirements is that not more than 10% of all five-minute calls on the global reference circuit will be disturbed at all, and not more than 1% will be disturbed for longer than 5 seconds, or by recurrent short fades. Naturally, the performance of a circuit shorter than the global reference circuit will be better.

This selection of performance objectives is based on engineering judgment. A more rigorous method of selecting values should be based on subjective testing of typical users to determine their tolerance to fade outages. Such data is not currently available but, when available, could be used to modify the requirements values used herein if deemed necessary. Other agency review of the chosen requirements values is also encouraged.

Each of the above requirements is imposed on the trans-CONUS common carrier and overseas terrestrial segments of the DCS global reference circuit of Section II. They are not applicable to satellite links, which do not have short fade outages but are normally either essentially unperturbed or unavailable. Thus, the satellite links are not allocated a portion of the fade outage budget. (Satellite channel quality requirements are imposed in the form of an overall unavailability specification and a maximum acceptable bit error rate.) Requirements (a) and (b) above may apply to either line-of-sight or troposcatter links. Since the majority of the CONUS common carrier portion of the DCS is line-of-sight radio relay, requirements (a) and (b) are allocated across the entire terrestrial segment, both overseas and CONUS, on a mileage basis. Requirement (c) above applies only to troposcatter links and is thus allocated among only the four troposcatter links which are included in the overseas terrestrial segment.

Thus, since there are four 600-mile reference channels in each of the CONUS and overseas terrestrial segments, the allocation of the overall requirements of (a) and (b) above to each 600-mile channel is 1/8 of the overall requirement. Since only the overseas segment contains troposcatter links, each overseas 600-mile channel is allocated 1/4 of the overall value of requirement (c) above, which applies only to troposcatter links. These

allocations are shown in the first column of Table II. A single line-of-sight link of nominal 30-mile length is 0.05 of the length of the 600-mile channel while a 180-mile troposcatter link is 0.3 of the length of the 600-mile channel. These percentages are used to obtain the per-link allocation of Table II.

The results of the above allocations are shown in Table II.

TABLE II. PROPOSED ALLOCATIONS OF FADE OUTAGE PROBABILITIES

	Ref. VF or Data Channel	LOS Link	Tropo Link
(a) Probability of fade outage (0.2 - 5 sec) per-call-minute	$2.5 \cdot 10^{-3}$	$1.25 \cdot 10^{-4}$	$7.5 \cdot 10^{-4}$
(b) Probability of fade outage (5 - 60 sec) per-call-minute	$2.5 \cdot 10^{-4}$	$1.25 \cdot 10^{-5}$	$7.5 \cdot 10^{-5}$
(c) Probability of recurrent outage rate of 2-5/min.	$2.5 \cdot 10^{-3}$	NA	$2.5 \cdot 10^{-3}$

b. *Mean Time Between Loss of Bit Count Integrity.* Bit count integrity is a parameter of primary interest in systems making widespread use of encryption equipment. Loss of bit count integrity, i.e., the accidental insertion of an extra bit into the bit stream or deletion of a bit from the bit stream, causes all affected encryption equipments to lose synchronization and thus require resynchronization. The outage penalty seen by the user due to this loss of synchronization is moderate if the crypto equipment is capable of automatically initiated resynchronization. If the crypto equipment is not capable of automatic resync, the outage penalty may be significant. All new crypto equipments being developed and deployed in the DCS, and essentially all crypto equipments operating at rates above teletype rate, are capable of automatic resynchronization. Many teletype rate channels are still encrypted with equipments which require manual resynchronization but loss of BCI due to transmisssion irregularities is not a significant threat for these channels since, for a considerable period into the future, the channels will be derived from VFCT equipment or low speed digital submultiplex equipment combined with a modem and applied to a VF interface with the transmission plant. The use of such an interface means that loss of BCI in the digital transmission path will cause errors but no loss of BCI in the teletype channels. Thus, the specified requirement for mean time between loss of BCI is based on considerations of how much losses of BCI will affect equipments with automatic resync capability.

It should be emphasized that the above discussion does not ensure the absence of problems due to manual resynchronization of encryption equipment. The point is made that the future system design is not being constrained by this possibility since (1) it is a diminishing configuration and (2) it does not appear to cause a problem. If problems do arise, they should be solved at the crypto or modem level rather than strongly influencing the design of the new digital transmission plant.

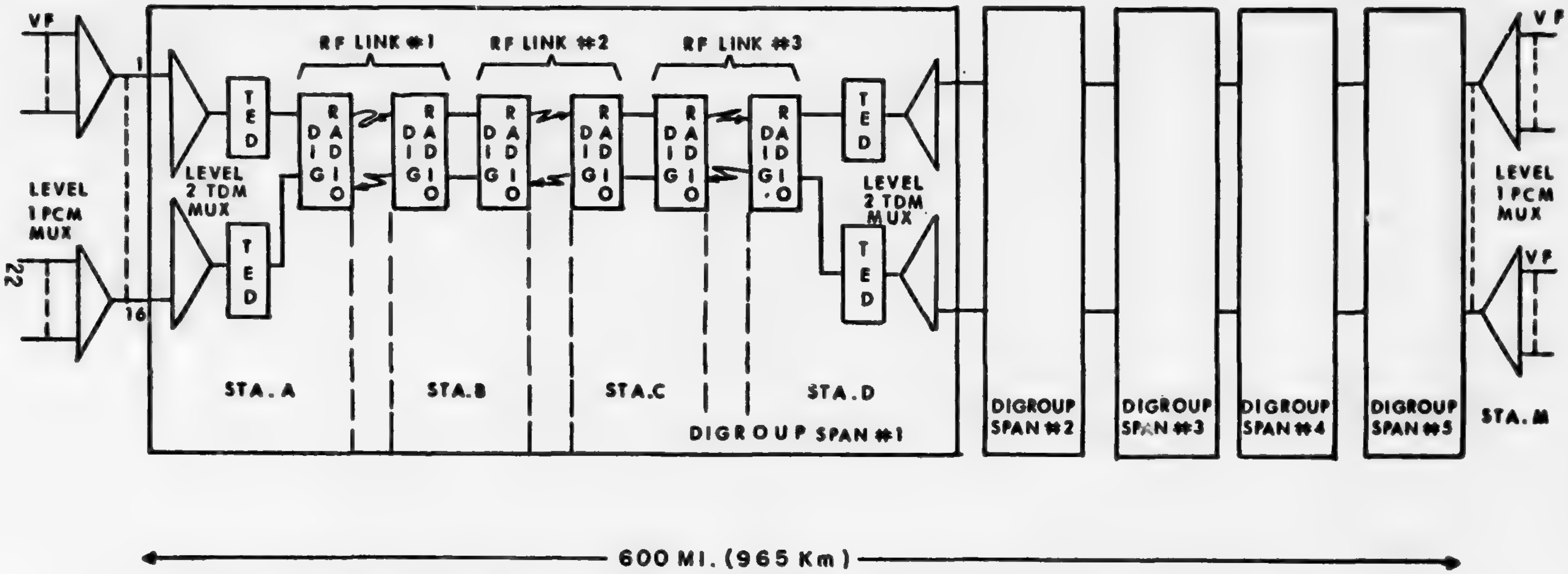
When BCI has been lost, resulting in the need for resynchronization, the length of time required for the resynchronization adds directly to the total duration of the outage. It is therefore of interest do determine the potential impact on overall service quality from outage extensions due to resynchronization. Consider the system block diagram of Figure 2. Assume that bit count integrity is lost on RF link #2 in the B to C direction due to a fade and a consequent loss of lock in the receiver bit timing recovery loop. The following actions then occur:

(a) RF link #3 may lose synchronization since bit timing of each link at an unattended repeater is slaved to the previous link bit timing.

(b) Both Level 2 Multiplexers at D associated with the Digroup Span #1 will declare loss of synchronization. When the error rate on the faded link has recovered sufficiently, the receiver at D will resynchronize. (Since the resynchronization process is probabilistic, dependent upon link error rate, the time required for this resynchronization is best described by a mean value as used in the table on the following page.) The Level 2 Multiplexers at D will attempt to resynchronize and, after an appropriate delay, will request the resynchronization of their Trunk (Bulk) Encryption Devices (TED). After the TED synchronization is completed, the Level 2 Multiplexers will resynchronize.

(c) Concurrent with the declaration of an out-of-sync condition at Station D, an out-of-sync condition will be detected by the Level 1 Multiplexer at Station M. If remote telemetry is provided to inform a link control unit (Transmission Status Monitoring and Control Unit--see Appendix A, paragraph 3.1.1.3.10 for description) at M of the fade outage in RF link #2, the Level 1 Multiplexer at Station M will have a delayed resynchronization to await the Level 2 resynchronization. Thus, there is the possibility that Level 1 resynchronization is not required. If remote telemetry is not provided, then the Level 1 Multiplexer at M will immediately initiate a resynchronization attempt and it will continue this attempt until synchronization is restored.

(d) It is important to note that Digroup Spans 2 through 5 remain in synchronization throughout the entire period. The frame for each of these digroup spans is generated in its Level 2 Multiplexer and detected in the corresponding Level 2 Demultiplexer. The fact that useless data crosses the 1.544 Mb/s interface between these digroup



NOTE: A DIGROUP SPAN IS THE COMMUNICATIONS PATH BETWEEN A PAIR OF LEVEL 2 MULTIPLEXERS.

FIGURE 2. DCS REFERENCE CHANNEL

spans does not affect the status of synchronization within the digroup span.

(e) For a digital user-to-user circuit such as an AUTOSEVOCOM II circuit, a submultiplexer, normally located with the Level 1 Multiplexer, will also need to resynchronize. Finally, the secure voice terminal, including the terminal crypto unit, will need to resynchronize.

The preceding actions describe the resynchronization effects that will result from a loss of BCI on an RF link. Although all individual circuits which occupy the affected RF link must then undergo a nested series of resynchronizations (as described above), no circuits elsewhere in the system that do not pass through the affected RF link are disturbed. The following is a list of the outage extension effect of a loss of BCI at the RF link:

Element	Mean Resync Time (Ms.)	
Digital Radio Sets (2)	10	(see Note 1)
Trunk (Bulk) Encryption Device (TED)	5	
Level 2 TDM Multiplexer	5	(see Note 1)
Level 1 PCM Multiplexer	25	
Digital (TDM) Submultiplexer	50	
Digital Secure Voice Terminal (DSVT)	500-1500 ms.	(see Note 2)
TOTAL:	595-1595 ms.	

NOTE 1: Mean resynchronization time for these units has been specified to be 25 ms, but, due to their operating bit rate, sufficient overhead capacity is provided such that their actual mean resync-time is expected to be considerably lower.

NOTE 2: The resynchronization time for the DSVT is approximately 1/2 second plus two round-trip path delays through the interconnecting channel. For non-satellite circuits, the round-trip path delay is trivial but for satellite circuits it is as much as 1/2 second, thus the time spread shown.

Of the above listed units, all except the TED and DSVT are capable of forward acting synchronization (i.e., a frame signal is sent continuously so that the receive end may resync without special cooperative action by the transmit end), whereas the TED and DSVT must enter into a cooperative resynchronization cycle (handshake).

The resynchronization period following a loss of BCI is therefore approximately 100 milliseconds for clear voice and other non-secure services and is approximately one second ($\pm$ 1/2 second) for secure voice service. This resynchronization period begins when link quality will support resynchronization with a high probability of success. Generally resynchronization can be accomplished prior to the time that the channel has returned to a usable level and

no outage extension will be attributed to the loss of BCI. For secure channels, the resynchronization period will normally extend the outage on the order of 1 second. In almost all instances, an outage will already exist, rather than the loss of BCI causing the outage.

To summarize the above discussion, losses of BCI are an important disturbance due to their effect on crypto synchronization. But, in equipments with automatic resynchronization capability, the principal impact of losses of BCI is to lengthen an existing outage by a moderate amount, and to make the channel error rate worse during their duration (since the channel error rate goes to 0.5 while BCI is lost). Due to the fact that BCI is almost invariably related to an already existing outage, it has been decided to specify performance objectives for loss of BCI as a percentage of fade outages; i.e., the percentage of fade outages that also result in a BCI loss. For line-of-sight fade outages, the resynchronization time is shorter than the existing outage time and the loss of BCI normally occurs when the error rate is already worse than 10% so that a moderately large number of outages can tolerate loss of BCI without materially decreasing the overall measure of channel quality. It has been decided to set 10% as an objective for the percentage of line-of-sight fade outages which cause a loss of BCI. Troposcatter fade outages are considerably shorter than line-of-sight outages and, during fading periods, are more frequent. Thus, a lower percentage of troposcatter fade outages may be allowed to cause a loss of BCI. An objective has been chosen that not more than 1% of all troposcatter fade outages should cause a loss of BCI.

c. Unavailability. The DCS end-to-end availability requirement of 0.99 was allocated in Section II, 2 to the various segments composing the global reference circuit. The unavailability allocation to the overseas terrestrial segment is 0.004. The overseas terrestrial segment is nominally composed of four, identical 600-mile (965 km) channels in tandem (see Section II, 1), each with an unavailability allocation of 0.001. This allocation must be appropriately divided between equipment outage and path outage contributions. Each will be discussed separately below.

Long-term path outages, suitable for inclusion in an unavailability allocation, are very rare on line-of-sight radio links. Such outages are not caused by multipath fading, but rather by anomalous index of refraction conditions. Multipath fading causes short outages which are considered a quality degradation as described in Section IV, 3,a rather than an unavailability. The total unavailability due to the occurrence of anomalous conditions is determined by the climatic characteristics of the path and by the degree of path clearance over the intervening terrain. This unavailability is expected to be considerably less than that due to equipment failure. A budget of 10% of the total channel unavailability is allocated to line-of-sight long-term path outage. This is a total allocation of 10^{-4} divided equally among 14 line-of-sight links or a per-link allocation of 7×10^{-6}. The path clearance criteria that must be applied to achieve this allocation is the subject of a separate, future report.

Long-term path outages are more frequent on troposcatter links than on line-of-sight links. Each 600-mile (965 km) channel in the reference overseas terrestrial segment contains one troposcatter link. An unavailability of 10^{-4} per 600-mile (965 km) reference channel is allocated to long-term troposcatter path outages. The remainder of the unavailability budget, $8 \cdot 10^{-4}$ per 600-mile (965 km) reference channel, is allocated to equipment failure outages.

The major factors which affect equipment-related unavailability are (1) the degree of equipment redundancy in the system, (2) the efficiency of performance monitoring techniques to detect and switch to standby equipment when failures occur, and (3) the logistics approach that is used to effect the restoral of failed equipments. Of these factors, the most important is the degree of redundancy. Effectively used redundancy allows nearly uninterrupted service when a single equipment fails.

The next most important factor in optimizing availability is the selected logistics approach. An adequate supply of spare modules or assemblies must be available on-site to avoid excessive downtime after a failure occurs. Also, personnel must be available to make the corrective action. Also, travel time is a very important factor in determining the mean-time-to service-restoral (MTSR). (Note the difference between MTTR which addresses only the time required to repair a unit, given that both personnel and parts are available, and MTSR which includes travel time and time to locate the appropriate part, plus the basic MTTR.)

The third major factor affecting unavailability is performance monitoring effectiveness. Performance monitors must be capable of detecting the failure of on-line redundant units and switching to the off-line unit but,even more importantly, they must be capable of detecting failures in an off-line unit so that it can be repaired before it is needed. Inability to detect an on-line equipment failure can be rectified by manually activated switchover to a standby equipment (hence a very short time-to-restore) but the inability to detect an off-line failure results in a total outage when the on-line unit subsequently fails. This occurrence results in the need to dispatch a maintenance man to physically repair the equipment before service is restored.

The above factors result in equipment-related availability being described in terms of four parameters:

(1) the mean-time-between-outages (MTBO) which can be restored by manual redundancy switching,

(2) the mean-time-between-outages (MTBO) which require equipment repair to accomplish service,

(3) the mean-time-to-service-restoral (MTSR) when an operational redundant unit is available, and

(4) the mean-time-to-service-restoral (MTSR) when actual equipment repair is required.

Of the above four factors, (3) can be assumed to be trivial relative to (4), and hence (1) is also trivial. In summary, the major factors which affect the unavailability of a system such as the DCS which widely uses redundancy are the percentage of undetected off-line equipment failures which nullify the advantage of redundancy, the manning density of the maintenance function which determines the travel time component of MTSR, and the adequacy of spare parts support.

The following discussion and its related Table III illustrate the effect of these factors on a reference 600-mile (965 km) channel in the DCS. Table III is an example of allocation of mean-time-between-outage (MTBO) requirements to individual equipment elements which meets the required availability allocation for a 600-mile (965 km) reference channel. These allocations to the equipment level are not mandatory but they represent the approximate order of magnitude of MTBO required to meet the specified unavailability and show which equipments exert the greatest leverage on overall availability. The 600-mile (965 km) channel model used in Table III is illustrated in Figure 2. Table III is also based on a number of assumptions listed below:

(1) The average LOS RF link will have an active cross-section of twelve digroups out of a possible maximum of sixteen since most DCS links are not fully loaded.

(2) The average digroup will have an active (i.e., assigned circuits) cross-section of 20 channels out of a possible maximum of 24. Thus the total cross-section used for availability calculations is twelve digroups times 20 channels or 240 channels.

(3) The mean-time-to-service-restoral (MTSR) once an equipment failure outage has occurred will be 30 minutes at an attended location and three hours at an unattended location. These assumptions are based on the attended restoral time being approximately twice the MTTR specified for each equipment due to the time lag in isolating the failure to a specific equipment, the time lag in getting maintenance personnel assigned, and delays in locating replacement modules or components. The three-hour MTSR period for unattended locations thus assumes a manning level which, on the average, locates repair personnel within 2 1/2 hours of the site. For the purposes of Table III, it is assumed that all locations containing multiplex and encryption equipment are attended while all other locations are unattended. Thus the MTSR values in Table III for all equipment failures except radio and station power are

TABLE III. REFERENCE CHANNEL UNAVAILABILITY ALLOCATIONS

EQUIPMENT	QUANT. (a)	NO. OF CHANNELS AFFECTED (b)	MEAN TIME TO RESTORE SERVICE (HRS) (c)	CHANNEL OUTAGE/ OUTAGE (HRS) (d = bxc)	MEAN TIME BETWEEN OUTAGES (HRS) (e)	OUTAGE RATE/ UNIT* ($f=10^6/e$)	TOTAL OUTAGES* (g=fxa)	CHANNEL OUTAGE (HRS)* (h=gxd)
DIGITAL RADIO SET	30	240	2.17	520	125,000	8	240	124,800
TRUNK (BULK) ENCRYPTION DEVICE	20	120	1/2	60	200,000	5	100	6,000
LEVEL 2 TDM MUX - COMMON EQPT.	20	120	1/2	60	200,000	5	100	6,000
LEVEL 2 TDM MUX - PORT EQPT.	120	20	1/2	10	220,000	4.5	540	5,400
LEVEL 1 PCM MUX - COMMON EQPT.	24	20	1/2	10	7,000	143	3,432	34,320
LEVEL 1 PCM MUX - CHANNEL EQPT.	480	1	1/2	1/2	170,000	6	2,880	1,440
STATION POWER**	16	240	1.75	420	500,000	2	32	13,440
				TOTAL CHANNEL HOURS/MILLION HOURS	2.4×10^8	TOTAL:		191,400
				TOTAL CHANNEL HOURS OUTAGE/MILLION HOURS	191,400			
				UNAVAILABILITY	.0008			

* PER MILLION OPERATING HOURS

**THE ASSUMED MEAN-TIME-BETWEEN-OUTAGES FOR STATION POWER IS BASED ON THE UNIVERSAL APPLICATION OF UNINTERRUPTABLE POWER SOURCES (UPS) AT ALL SITES. THE STANDARD UPS PROVIDES BACKUP ROTARY GENERATION CAPABILITY WITH A BATTERY PLANT TO CARRY THE STATION LOAD DURING THE GENERATOR STARTUP PERIOD.

30 minutes and the MTSR values for radio sets and station power result from the fact that 1/3 of all radio sets and station power equipment are at attended locations (Station A and D of Figure 2) while the other 2/3 are at unattended locations (Stations B and C). The resultant MTSR for radio and station power equipment derives from averaging these values (2.17 hours for Digital Radio Sets and 1.75 hours for Station Power).

(4) Unavailability due to equipment failures will result only from those equipment failures which actually cause a service outage. For redundant equipment, most failures do not cause an outage and therefore have no impact on unavailability. Mean-time-between-outages is the measure of how often an equipment, even if redundant, causes an outage. Typical causes of outage in redundant equipments are failures of the standby equipment which are not detected until the on-line unit fails, or failure of the redundancy switching circuitry to correctly detect the need to switch. In order to provide an acceptable unavailability, it is clear that the Digital Radio Set, the Level 2 TDM Multiplexer, and the Trunk (Bulk) Encryption Device must be redundant (see Table III) due to the number of channels that are affected when these units fail, and to the number of these units that each channel must traverse. (Effective redundancy can be obtained for the Trunk (Bulk) Encryption Device with a bypass arrangement since a short term loss of trunk encryption is not considered to be an outage.)

The values shown in Table III were derived as follows:

(a) Quantities in column (a) were obtained from Figure 2.

(b) The number of channels affected by each outage listed in column (b) were computed from assumptions (1) and (2) above.

(c) Mean-Time-to-Restore-Service (MTSR), column (c), was derived as discussed in (3) above.

(d) Channel Outage/Outage listed in column (d) is the product of the Number of Channels Affected (b) and MTSR (c).

(e) Mean-Time-Between-Outages (MTBO) values listed in column (e) were assigned based on the considerations discussed in assumption (4) above. These assignments are not mandatory but they are felt to be typical of those required to meet the overall system availability requirement.

(f) Outage Rate/Unit is expressed per million operating hours, thus it is equal to 10^6 divided by MTBO.

(g) Total Outages listed in column (g) is the product of Quantity (a) and Outage Rate/Unit (f).

(h) Total Channel Outage listed in column (h) is the product of Total Outages (g) and Channel Outage/Outage (d).

(i) Total Channel Hours is the product of the total channel cross-section times one million operating hours, i.e., $240 \times 10^6 = 2.4 \cdot 10^8$.

Note that columns (f), (g), (h), and the term, 'Total Channel Hours', are all based on one million hours of system operation. This period, one million hours, is simply a convenient unit for calculation purposes. It is cancelled out in the division process of dividing Total Channel Hours of Outage by Total Channel Hours to obtain Unavailability.

Based on the values of MTBO and MTSR assumed herein, unavailability allocations have been made to the individual RF link and reference digroup in the system specification. These allocations are obtained by adding the individual unavailability contribution of each equipment composing the RF link or digroup where unavailability is approximately equal to the MTSR divided by the MTBO of the equipment. An actual implementation may be chosen which deviates slightly from the assumptions used herein. Such a deviation is acceptable if the resultant channel unavailability, derived by the method developed herein, is still no greater than 0.0008.

d. Link Design - Line-of-Sight. Fading on line-of-sight links may occur due to either multipath propagation or anomalous index of refraction effects. Fade margin is normally provided to combat multipath fading while adequate path clearance is the normal protection from anomalies. Path clearance requirements bear a complex relationship to climate and terrain which are not treated herein. The following discussion treats the derivation of fade margin requirements.

The primary performance requirement which imposes a specification requirement for fade margin is the probability of fade outage. From Section IV,3,a, on a single line-of-sight link, the requirement for probability of fade outage is $1.25 \cdot 10^{-4}$ for outages in the 0.2 - 5 second range, and $1.25 \cdot 10^{-5}$ for outages in the 5 - 60 second range.

These performance requirements replace the RF link design criterion termed "media unavailability", which was previously used as the DCS link design standard. The overall link designs that result from using the fade outage probability criterion vice the media unavailability criterion are similar, although they may differ by a few dB from link-to-link. The primary reason for changing from the "media unavailability" criterion to the probability-of-fade-outage criterion is to provide better traceability to specific

circuit performance as perceived by the user. Appendix C contains a comparison of the two criteria for a specific RF link to allow comparison with previous link designs.

Link design will be discussed herein based on fade margin as the fundamental design parameter. Performing link designs based solely on fade margin assumes that the line-of-sight channel is sufficiently non-dispersive so that media-caused intersymbol interference is a negligible error source. For properly designed links, at the transmission rates to be used in the DCS, this is a valid assumption. Intersymbol interference in this context is caused by a linear time dispersive propagation path where the transmitted symbol stream is dispersed resulting in overlapping of these symbols at the receiver. Generally, the amount of channel dispersion (i.e., the width of its impulse response) must be on the order of 10-20% of a transmitted symbol (i.e., baud) interval for channel-caused intersymbol interference to become significant. For DCS links, the highest baud rate will be on the order of 1/2 the bit rate or about 12.5 megabaud per second. This corresponds to a baud interval of 80 nanoseconds with a corresponding required channel multipath delay spread of 8 nanoseconds or more to cause significant intersymbol interference effects. Typical multipath delay spread for line-of-sight paths is on the order of 2 nanoseconds [1] and thus should cause no significant impact. [A recent report [2] reported significant intersymbol interference on a digital microwave path in Colorado but an examination of the distribution of long-term hourly median path loss values on this path leads to the suggestion that the path had inadequate terrain clearance and that the reported large values of delay spread occurred when the path was operating in a diffraction mode rather than a line-of-sight mode. In diffraction mode, particularly in mountainous terrain, the opportunity arises for transmitted energy to reach the receiver via significantly off-axis reflective paths with consequently high delay spread.] Fade margin is defined as the difference, in dB, between the median, unfaded received signal level and the threshold received signal level corresponding to a 10^{-4} bit error probability. The probability that the received signal level is below threshold on a space diversity RF link can be expressed in terms of fade margin by [3]:

$$P_o = \left(r^2 + \frac{1}{r^2}\right) \frac{acD^4}{56S^2} 10^{-F/5} \tag{1}$$

where P_o = the probability that the received signal is below threshold.
- a = the percentage of the year that constitutes the fading season.
- c = climate and terrain factor. This parameter may vary from 0.25 to 4 with a value of 1 for average terrain and climate.
- D = path length in statute miles.
- S = antenna separation (diversity) in feet ($S \leq 50$ feet).
- F = fade margin in dB.
- r^2 = diversity combiner hysteresis ratio ($10 \log r^2$ = hysteresis ratio in dB. This is the difference in diversity signal level required for the diversity switch to operate).

(See reference [3] for an excellent discussion on the proper application of the factors a and c, to various types of terrain and climate, for the estimation of the proper value of the length of the fading season and for criteria for the selection of path clearance requirements.)

An expression similar to (1) can be obtained for frequency diversity operation. In this case, the factor S^2 in (1) is replaced by

$$S^2 = \begin{cases} \dfrac{7D \times \Delta f}{f^2} & \text{in the 4 GHz band} \\[2ex] \dfrac{1.75D \times \Delta f}{f^2} & \text{in the 8 GHz band} \end{cases} \qquad (2)$$

where D = path length in miles
Δf = frequency separation in MHz
f = frequency in GHz.

A moderate amount of test data has been obtained [4] on the distribution of line-of-sight fade durations. The resulting fade duration distribution for diversity reception has a mean value given by

$$t_o = 225 \times 10^{-F/20} \qquad (3)$$

where t_o is the mean duration of fades below threshold, in seconds, and F is the fade margin in dB. Expressions have been derived for the curve that best fits empirical data on the distribution of fade durations relative to their mean value [4] and [5] . The simpler of these expressions will suffice for use herein and is given by:

$$P(t) = e^{-1.15(t/t_o)^{2/3}} \qquad (4)$$

where $P(t)$ is the probability that a fade has a duration of t seconds or greater. Figures 3, 4 and 5 illustrate the relationships of equations (1) through (4) and are provided for background illustration.

For a given fade margin, the mean-time-between-fade-outages in seconds can be obtained from

$$\text{MTBFO} = \frac{t_o\,(1 - P_o)}{P_o} \simeq \frac{t_o}{P_o} = \frac{1.26 \times 10^4\, S^2}{(r^2 + \frac{1}{r^2})acD^4}\, 10^{0.15F} \qquad (5)$$

Thus, for example, the mean-time-between-fade-outages on a 30-mile (48 km) space diversity path, with 30-foot (9.1 m) antenna separation, a 2 dB hysteresis, and a 30-dB fade margin, is 8×10^5 seconds or 9.15 days.

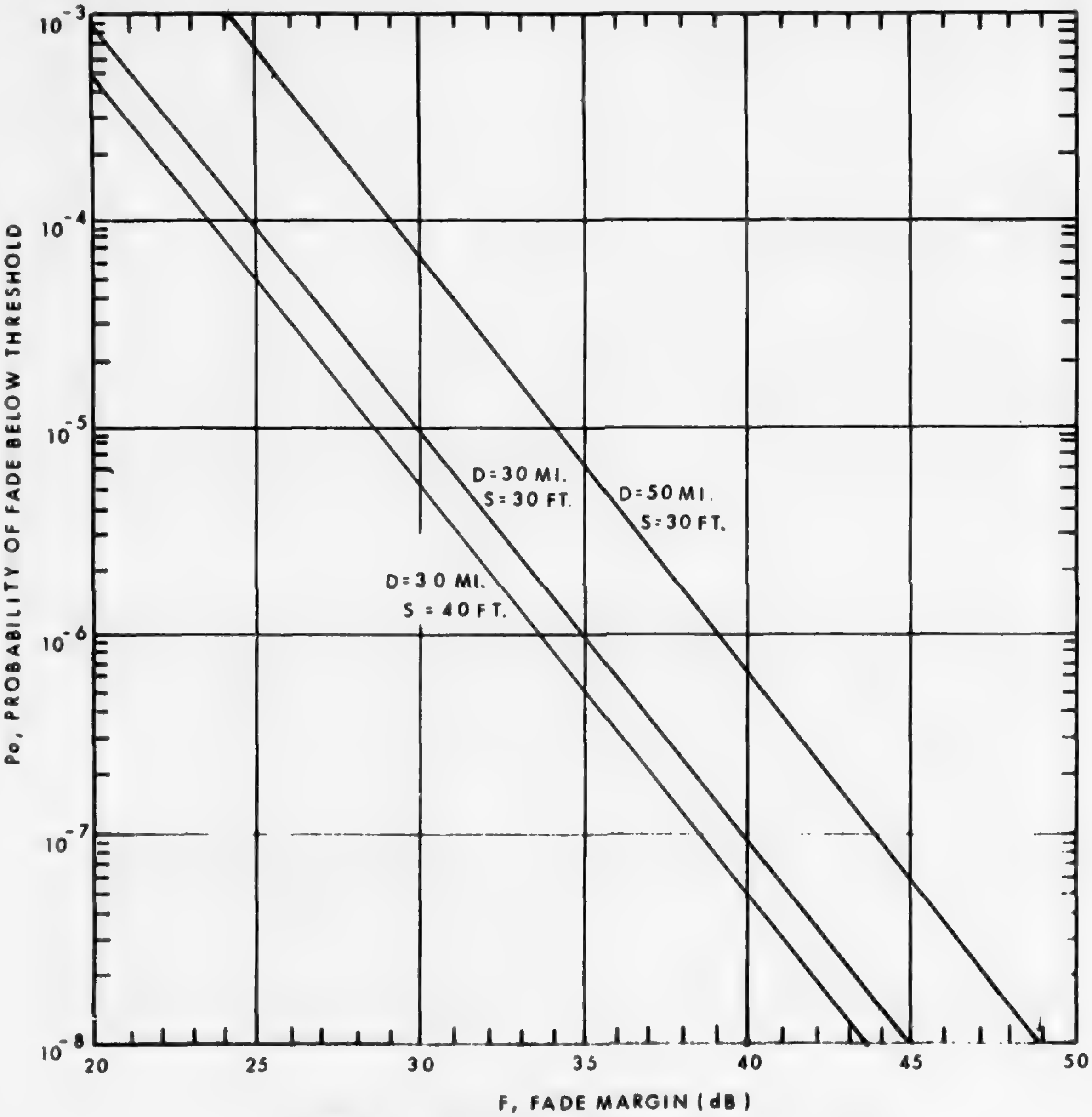


FIGURE 3. ANNUAL PROBABILITY OF FADING BELOW THE FADE MARGIN ON TYPICAL LOS LINKS (3 MO. FADING SEASON, AVERAGE TERRAIN AND CLIMATE, 2 DB DIVERSITY HYSTERESIS)

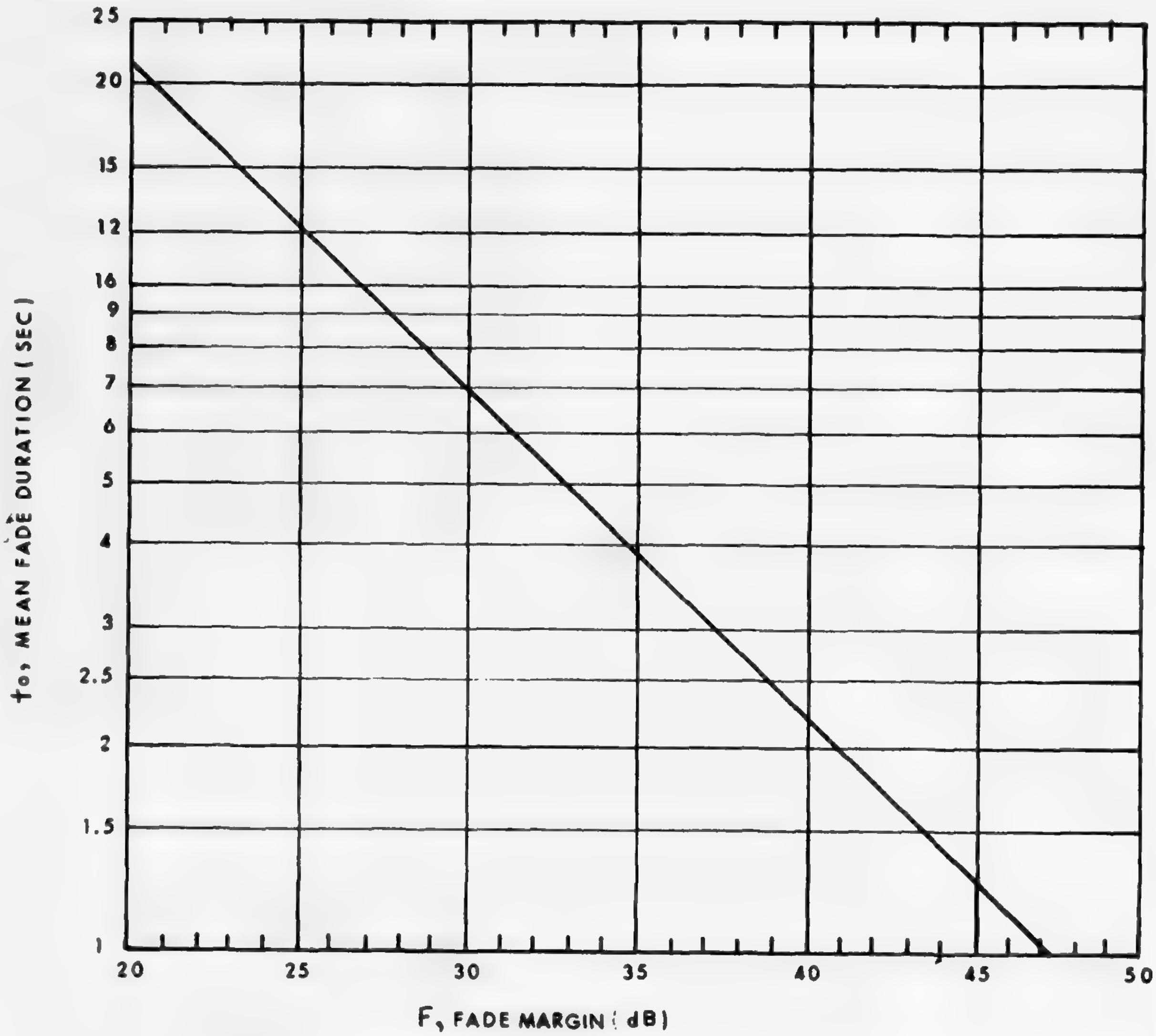


FIGURE 4. MEAN FADE DURATION ON DIVERSITY LOS LINKS

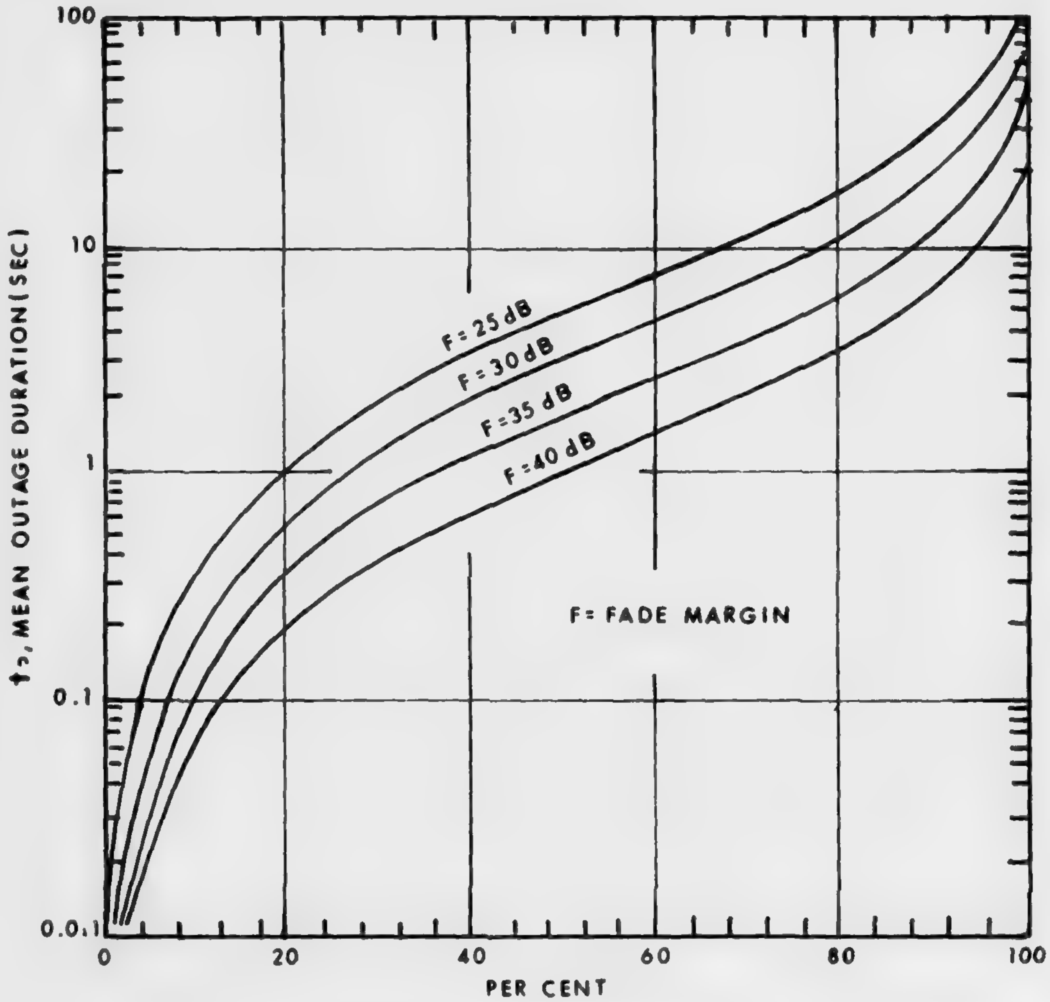


FIGURE 5. PERCENT OF DIVERSITY LOS FADES WITH DURATION LESS THAN ORDINATE

Out of the total set of fades, the percentage with duration in the range from 200 milliseconds to 5 seconds and the percentage with duration in the range above 5 seconds can be obtained from (4). Thus the mean-time-between-fade-outages in seconds for any particular range of fade duration is

$$\text{MTBFO}\ (t_1, t_2) = \frac{\text{MTBFO}}{P(t_1) - P(t_2)} \tag{6}$$

where MTBFO is the mean-time-between-fade-outages of any duration, obtained from (5), t_1 and t_2 are the lower and upper duration limits, respectively, and $P(t)$ is given by (4). The number of fade outages of a given range of fade duration during a call duration of one minute, assuming a 100% channel activity factor (this is equivalent to duplex operation), is given by

$$n = \frac{60}{\text{MTBFO}\ (t_1, t_2)} \cdot \tag{7}$$

For small values of n, this is approximately equal to the probability of fade outage per call-minute. Since for all reasonable link designs MTBFO (t_1, t_2) will be much larger than 60, the probability of fade outage on the link can be considered to be equal to n.

Table IV is a summary of key parameters relating to fade outage probability over a range of fade margins for a typical link. (Table IV was calculated for a 30 statute mile (48 km) path with 30-foot (9.1 m) space diversity antenna separation and a hysteresis value of 2 dB.) Figure 6 shows the probability of fade outage per call-minute (plotted from columns F and G of Table IV) for the 0.2 - 5 second and the greater-than-5-second range of outages. Referring to Section IV, 3,a, Table II, the requirements for Range II (0.2 - 5 second) and Range III (greater-than-5-second) duration fade probabilities are $1.25 \cdot 10^{-4}$ and $1.25 \cdot 10^{-5}$, respectively. Thus, from Figure 6, the fade margin required to meet these requirement is 26 dB for the 0.2 - 5 second requirement and 32 dB for the over-5-second requirement. To determine the fade margin required for a specific link, the more stringent of the two requirements governs and the fade margin for the specified link is therefore 32 dB. Figure 6 shows that, in the practical range of fade margins (20-45 dB), since the basic requirement for fade outages longer than 5 seconds is ten times more stringent than the requirement for shorter fade outages, the requirement for longer fade outages always dominates the choice of fade margin.

A curve showing the cumulative fade probability, P_0 of equation (1), is also plotted in Figure 6. This parameter, P_0, is the same as the "media unavailability" previously used as a link design criterion. The curve for P_0 has nearly the same slope as the curve for outage Range III fade outage probability. Thus, they are similar parameters that can be

TABLE IV. PROBABILITY OF FADE OUTAGE FOR VARIOUS FADE MARGINS

A	B	C	D	E	F	G
F (Fade Margin) dB	to (Mean Fade Duration) sec. (from Fig. 4)	P_o (Total Outage Probability) (from Fig. 3)	P(0.2)-P(5) (% Outages between 0.2 and 5 sec.) (from Eq. 4)	P(5) (% Outages longer than 5 sec.) (from eq. 4)	n_{II} Prob. of 0.2-5 sec. outage/call minute (from Eq. 7)	n_{III} Prob. of over 5 sec. outage/ call minute (from Eq. 7)
20	22.5	9×10^{-4}	29	66	7×10^{-4}	1.6×10^{-3}
25	12.6	9×10^{-5}	39	54	1.7×10^{-4}	2.3×10^{-4}
30	7.1	9×10^{-6}	50	40	3.8×10^{-5}	3×10^{-5}
35	4	9×10^{-7}	60	26	8.1×10^{-6}	3.5×10^{-6}
40	2.25	9×10^{-8}	66	14	1.6×10^{-6}	3.4×10^{-7}

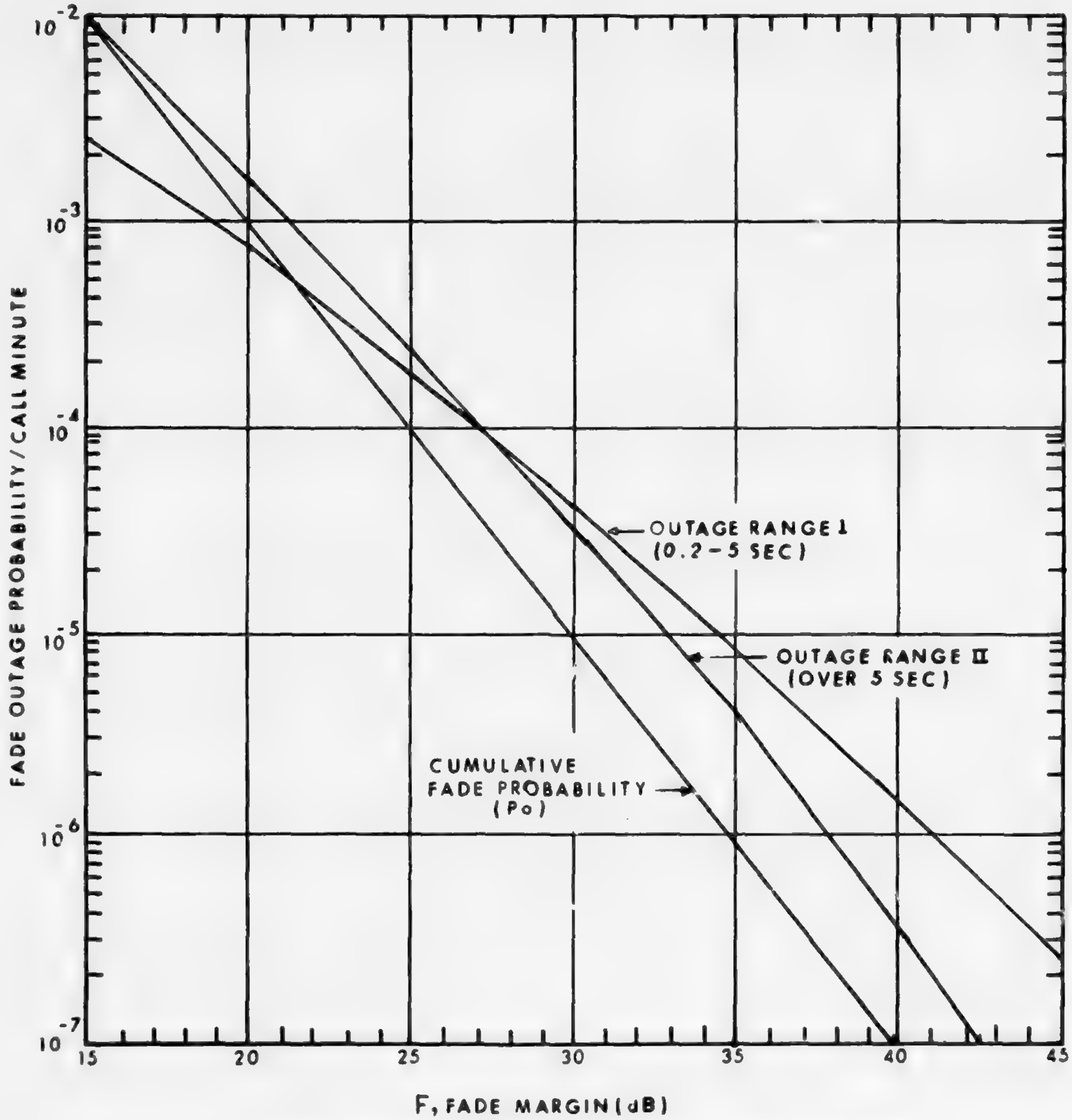


FIGURE 6. FADE OUTAGE PROBABILITY/CALL-MINUTE FOR A 30 MILE, SPACE DIVERSITY LOS LINK

used interchangeably, with a suitable adjustment factor over the range of interest. The previously used link design criterion of $P_0 = 10^{-5}$ resulted in a fade margin requirement of 30 dB for the link described by Figure 6, whereas the probability of fade outage requirement results in a fade margin of 32 dB. A 32 dB fade margin, on this link, is equivalent to a "media unavailability" of 3.5×10^{-6}. Hence, links may be designed using the "media unavailability" criterion if a value of $3.5 \cdot 10^{-6}$ is used as the required value.

The above derivation leading to a fade margin requirement is dependent on individual RF link parameters, because the evaluation of the probability of the received signal being below threshold, P_0, is affected by link characteristics. The fade outage probability is directly proportional to P_0 so that differences in path length, antenna separation, terrain, and climate result in a vertical displacement of the curves in Figure 6 that is determined by the ratio of the P_0 of the actual link to the P_0 of the referenced link of Figure 6.

Figure 6 is plotted for average terrain, average climate, a 30 statute mile (48 km) path and a 30-foot (9.1 m) antenna separation.

Table V illustrates the impact on required fade margin of various path parameters.

TABLE V. FADE MARGINS FOR VARIOUS PATH PARAMETERS

PATH			
Length (mi)	Diversity Separation (ft)	Climate & Terrain	Required Fade Margin (dB)
30	20	Normal (ac=1/4)	34
30	30	Normal (ac=1/4)	32
30	40	Normal (ac=1/4)	30.5
30	30	Good (ac=1/32)	26.5
30	30	Poor (ac=2)	33.5
40	30	Normal (ac=1/4)	34.5
50	30	Normal (ac=1/4)	36.5
50	40	Good (ac=1/32)	30.5
50	40	Poor (ac=2)	39.5

To determine the total link margin required on any specific RF link, equation (1) is used to find the required value of fade margin, F, for $P_o = 3.5 \times 10^{-6}$, using values for r, a, c, D and S that are tailored to the particular link in question. A miscellaneous loss margin of 6 dB is required in addition to the fade margin derived above. This miscellaneous loss margin is required to account for initial link implementation losses such as minor antenna misalignment, to account for system gain degradation such as waveguide corrosion and receiver noise figure aging that occur over the lifetime of the system and to allow for the effects of RF interference.

The above criterion will result in the overseas and CONUS terrestrial digital transmission segments causing an average of not more than 1% of all five-minute calls via the global reference circuit to be perturbed by a disruptive fade outage (longer than 5 seconds). Since the terrestrial segments of the global reference circuit are nominally composed of eight identical 600-mile (965 km) VF channels (i.e., assuming the CONUS segment is identical to the overseas segment), these channels will, on the average, experience a 5-second or longer disruption on not more than 0.125% of all 5-minute calls. This is a yearly average value. The fading which causes these disruptions is actually a somewhat seasonal phenomenon and also is more likely to occur at certain times of the day. For the 600-mile VF channel, the worst fading hour may be about one order-of-magnitude worse than the yearly average, therefore making the probability of fade outage during the worst hour for the 600-mile channel similar to the annual average value of the global reference circuit. The variation of global reference circuit performance around its average value will not be as great since, due to its length, it spans many time zones and may even span regions with opposite seasons.

e. <u>System Gain - Line-of-Sight</u>. System gain is the difference between the power output of the transmitter, as delivered to the transmit waveguide, and the sensitivity of the receiver as measured at its interface with the receive waveguide. Receiver sensitivity is that received signal strength required to meet the threshold bit error rate requirement of 10^{-4}. (Some previous documents have referred to a bit error rate threshold of 10^{-9}. Either threshold is usable by applying a correction factor of 4 dB; i.e., fade margin and system gain numerical requirements are reduced by 4 dB if the threshold is referred to a 10^{-9} bit error rate rather than the 10^{-4} bit error rate used herein.)

For a line-of-sight path, the required system gain is given by

$$G_s = L_{fs} + F + L_w + L_m - G_{at} - G_{ar} \tag{8}$$

where G_s = system gain in dB
L_{fs} = free space path loss in dB
= 97 + 20 log f + 20 log D (f and D are frequency and path length as previously defined)
F = fade margin in dB

L_w = total waveguide loss in dB
L_m = miscellaneous losses due to atmospheric absorption, waveguide aging, receiver noise figure aging, etc.
G_{at} = transmitting antenna gain
G_{ar} = receiver antenna gain.

In order to obtain values for these parameters which represent a broadbased sample of the DCS, records of approximately 70 existing microwave links in the European DCS were surveyed. L_{fs} was calculated based on path length records, L_w was calculated based on waveguide length records, G_{at} and G_{ar} were calculated based on antenna size records, and a value of 6 dB was assigned for L_m. For each surveyed RF link, a combined net path loss value, L_t, was obtained from

$$L_t = L_{fs} + L_w + L_m - G_{at} - G_{ar} . \tag{9}$$

The distribution of values of L_t is plotted in Figure 7. Figure 8 is a similar plot for the distribution of path lengths for the same set of links.

A system gain requirement of 104 dB is derived from Figure 7 in order to provide at least 32 dB fade margin on 90% of all RF links without requiring antenna replacement. This replacement will allow digital upgrades of most existing sites without the need to install larger antennas.

f. Error-Free Data Blocks - Line-of-Sight. The specified requirement for error-free data blocks for a reference line-of-sight link is 0.99997 (see Section IV,2,b). This corresponds to a $3 \cdot 10^{-5}$ probability that any block will contain errors. This probability is given by [6].

$$P\ (BE) = \sum_{k=1}^{n} \int_{0}^{0.5} \binom{n}{k} p^k (1-p)^{n-k} f(p)\, dp \tag{10}$$

where n = the number of bits in a data block
k = the number of errors in the block
p = bit error probability
f(p) = the probability density function of the bit error probability for the specified channel.

In the above expression, the term

$$\sum_{k=1}^{n} \binom{n}{k} p^k(1-p)^{n-k} \tag{11}$$

represents the probability that a block will have one or more errors, given a bit error probability, p. The remainder of the expression evaluates the probability that, for a specific channel, the bit error probability will have a value, p. Since the channel is a dynamically fading channel,

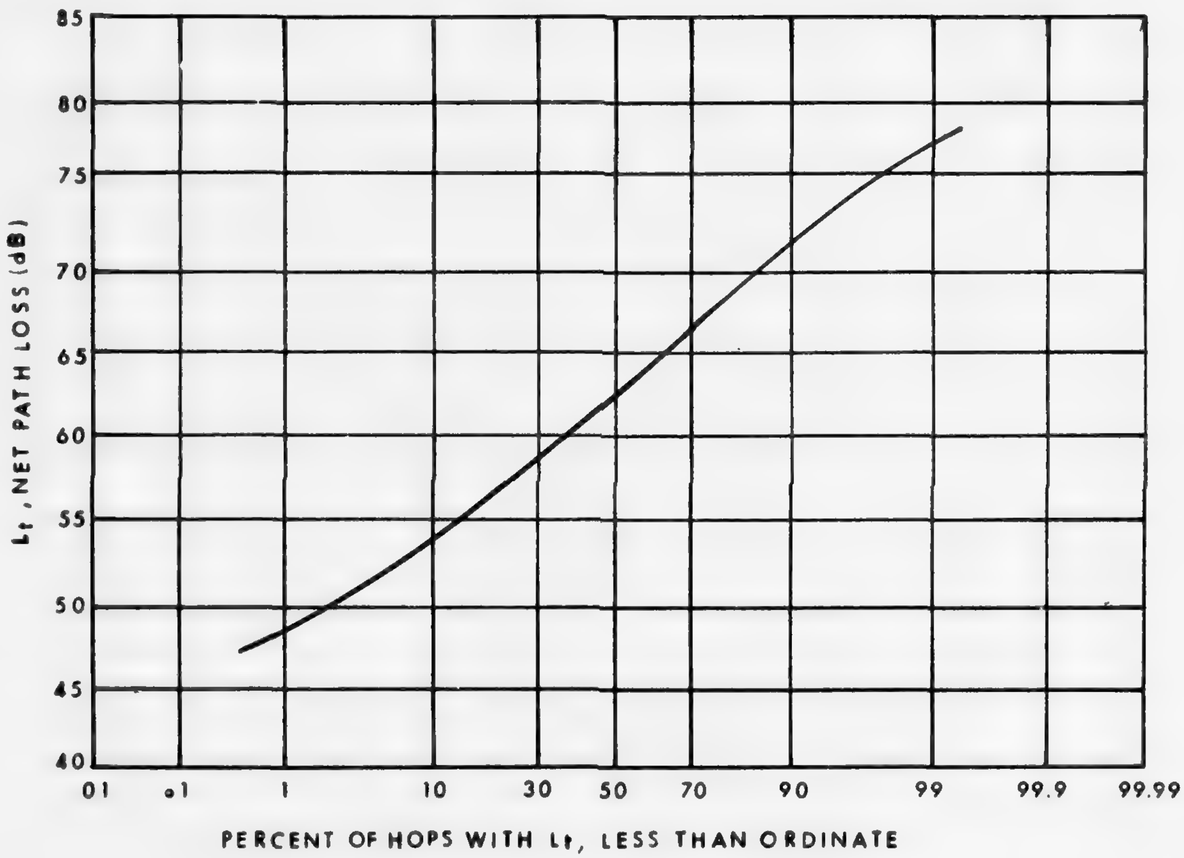


FIGURE 7. DISTRIBUTION OF NET PATH LOSS, L_T, FOR 70 SELECTED EUROPEAN DCS LOS LINKS

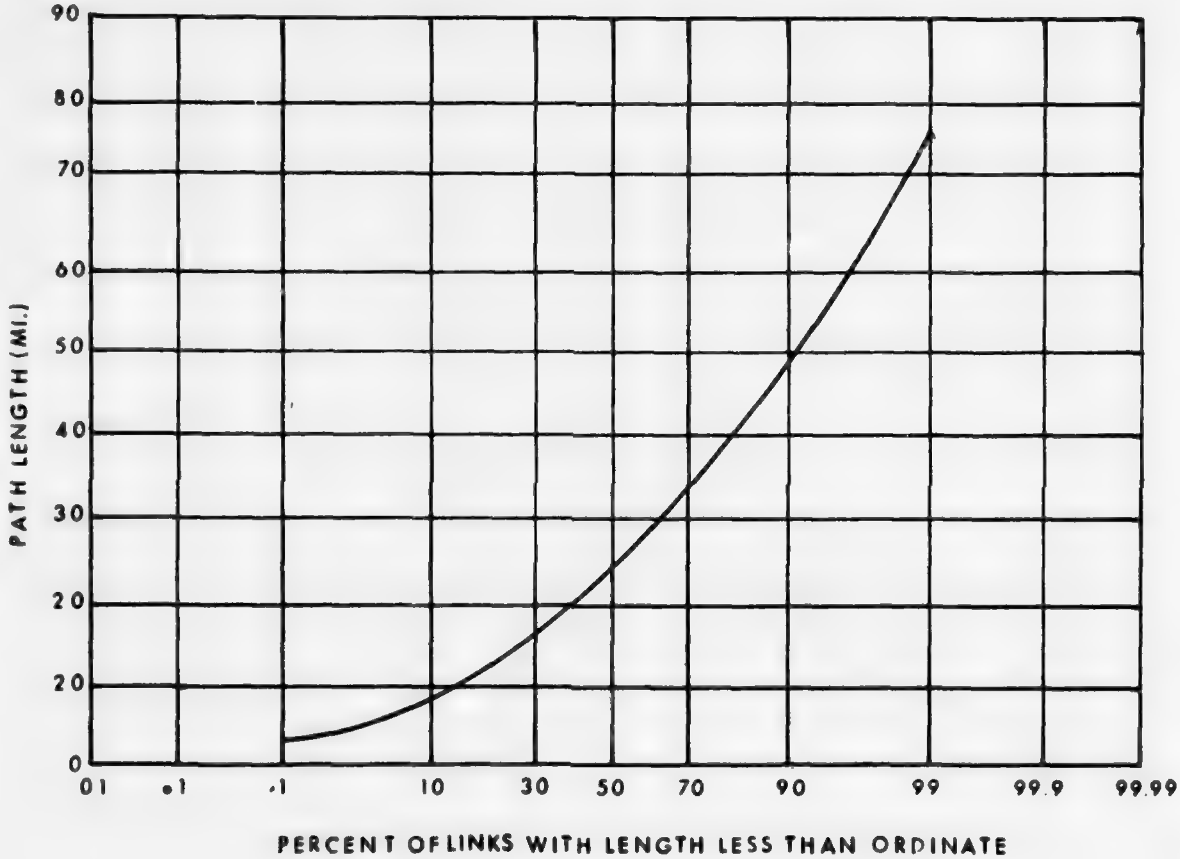


FIGURE 8. DISTRIBUTION OF PATH LENGTH FOR 70 SELECTED EUROPEAN DCS LOS LINKS

the evaluation of the expression for P(BE) can be thought of as determining the percent of time that the received signal level occupies some value that corresponds to a particular bit error probability, and then determining, for each of those time increments, how many of the transmitted blocks can be expected to contain errors. The former percentage, i.e., percent of time that the received signal level is at some value, is a direct function of the fade margin, and hence P(BE) is a function of fade margin.

Rigorous evaluation of the expression (10) is quite difficult but approximate evaluation can be made with acceptable accuracy by observing the following:

(1) For a given modulation technique and a given RF link configuration, f(p) can be converted by a transformation of variables to an equivalent density function of received signal level, f(RSL).

(2) The value of the expression (11) for block error conditional probability goes rapidly from a trivial value to approximately unity over about a 2 dB RSL range in the immediate vicinity of that RSL which corresponds to a bit error probability of $p = \frac{1}{n}$.

(3) The value of f(RSL) is Rayleigh distributed, hence the probability that the RSL occupies a small region ($RSL \pm E$) around any specified value does not vary greatly as the specified RSL is varied.

(4) Therefore, the probability of block error is approximately equal to the probability that the fade depth exceeds that RSL threshold where bit error probability is $\frac{1}{n}$.

Thus, for the block length of 1000 bits, the threshold bit error probability for block errors is 10^{-3}. The RSL corresponding to this value of bit error probability is 1.6 dB below the threshold RSL defined in section IV, 2,a. The probability of a fade exceeding this block error threshold can be obtained for any RF link by first determining the link fade margin, F_1, using the methods of section IV, 3,d. The probability of block error for the link is given approximately by

$$P(BE) = P_o(F_1) \cdot 10^{-1.6/5} \qquad (12)$$

where P_o (F_1) is the fade margin requirement of Section IV,3,d or $3.5 \cdot 10^{-6}$. For a 30-mile (48 km) link over average terrain and climate, with 30-foot (9.1 m) antenna separation, the resultant required fade margin (from IV,3,d) is 32 dB and the resultant predicted probability of block error is $1.7 \cdot 10^{-6}$. Note that this predicted probability of error-free blocks, which results from the fade margin requirement imposed by voice channel quality requirements, is much better than the data channel requirement specified in Section IV,2,d. Thus, the voice channel requirement imposes a more stringent demand on fade margin than does the data channel requirement. The predicted performance of the global reference circuit, based on extrapolation of the above calculated RF link block error probability, is a 0.9996 probability of error-free seconds. This calculated value considers only fade-induced errors. A small percentage of additional errors will be caused by fade outage extension at the digroup and channel level due to resynchronization periods added to the end of some fade outages (see Section IV,3,b) and occasional error bits due to redundant equipment switching and unexplained transients. Nevertheless, overall error-free block performance is expected to be at least 0.999.

g. Link Design-Troposcatter. The troposcatter channel is most accurately viewed as having a compound fading characteristic with short term (e.g., hourly) Rayleigh fading impressed on a longer diurnal and annual fading distribution. Historically, the performance of troposcatter links was related to the percentage of time that a particular short term average Signal-to-Noise Ratio ($\overline{SNR}$) could be maintained out of the longer term fading ensemble (i.e., time availability). The essence of this convention will be continued here.

Determination of the long-term distribution of short term $\overline{SNR}$s is extensively and accurately covered in the literature [7], [8] and therefore it is unnecessary to repeat the methodology here. Thus the following paragraphs will concentrate on the characterization and specification of short term digital performance (e.g., on an hourly basis), as a function of the short term $\overline{SNR}$. This parameter, short term $\overline{SNR}$, will be denoted throughout this discussion by the symbol, γ_0. The γ_0 necessary to obtain a specified short term performance (here described on the basis of acceptable outage rates and duration) will then be described in unavailability fashion (i.e., to be maintained for all but a certain percentage of time) and converted into required system gains for various DCS digital troposcatter configurations. The performance criteria to be used in these determinations are indicated in Table VI. Both quad diversity and dual diversity systems are modeled against these criteria with the most demanding criteria (in the long-term sense) determining link design requirements. Additionally, since outage statistics are dependent on the fade rate of the transmission channel, the performance of both quad and dual diversity systems will be characterized at mean fade rates (N) of .1 and 5 Hz. This range of mean fade rates is inclusive of the fade rates observed on most L and C-Band links [9] . The alphabetical band designators are meant to descirbe the 755-985 and 440-5000 MHz bands, respectively. For links operating in the S-Band (1700-2400 MHz), the link design requirements for L-Band systems, developed herein, will apply.

TABLE VI. DCS PCM VOICE PERFORMANCE CHARACTERISTICS

A OUTAGE RANGE	B CRITERIA	C OUTAGE PROBABILITY
II	$.2 \text{ sec} \leq \text{outage} < 5 \text{ sec.}$	$7.5 \cdot 10^{-4}$
III	$5 \text{ sec} < \text{outage} < 1 \text{ min.}$	$7.5 \cdot 10^{-5}$
IV	$2 < \text{outages/min.} < 5$	$2.5 \cdot 10^{-3}$
V	$5 < \text{outages/min.}$	$1 \cdot 10^{-4}$

NOTE: The Outage Ranges listed in Column A and the Criteria listed in Column B were previously defined in Sections IV,2,a and IV,2,b, respectively.

The short-term probability that the diversity combined signal in a troposcatter system will fall below the 10^{-4} bit error rate threshold, can be obtained via the methods of [9]. This probability, P_o, is given by

$$P_o = 1 - b \sum_{R=1}^{m} \frac{\ell^{R-1}}{(R-1)!} \tag{13}$$

where P_o = probability of an outage given a short-term SNR, γ_o

$b = (2P_e)^{2/\gamma_o} = (2 \times 10^{-4})^{2/\gamma_o}$

$\ell = -\ln b$

γ_o = short term $\overline{\text{SNR}}$ (actual ratio, not in dB)

$m = \text{total diversity} = \begin{cases} 4, & \text{dual diversity} \\ 8, & \text{quad diversity} \end{cases}$

The above value for m is numerically twice the order of explicit diversity due to the presence of an "implicit diversity" advantage. Digital troposcatter modems take advantage of decorrelated fading between various portions of the transmitted spectrum to gain this additional diversity advantage. For most DCS troposcatter paths, the expected implicit diversity gain is expected to be on the order of 2, hence the above values for m. These performance analyses will consider both dual and quad explicit diversity. Although quad diversity will continue to be the dominant troposcatter configuration in the DCS, parallel transmission of two separate bit streams through dual diversity could be used to obtain the needed throughput in the 1 and 2 GHz bands where lack of wideband frequency allocations might otherwise prohibit high rate digital operation.

The expression for P_o is based on the relationship between bit-error-rate and SNR for DPSK modulation. This allows the expression of P_o in terms of γ_o which is the parameter normally used in troposcatter link design. A conversion factor is provided later to allow the finally derived link design requirement to be converted for any other type of modulation. Figure 9 is a plot of (13) illustrating P_o for dual and quad diversity operation.

Having characterized cumulative outage probability, it is now appropriate to examine the temporal distribution of outages. Again using the expressions developed in [9], mean outage duration and frequency statistics can be expressed for diversity troposcatter transmission by

- Mean Outage Rate

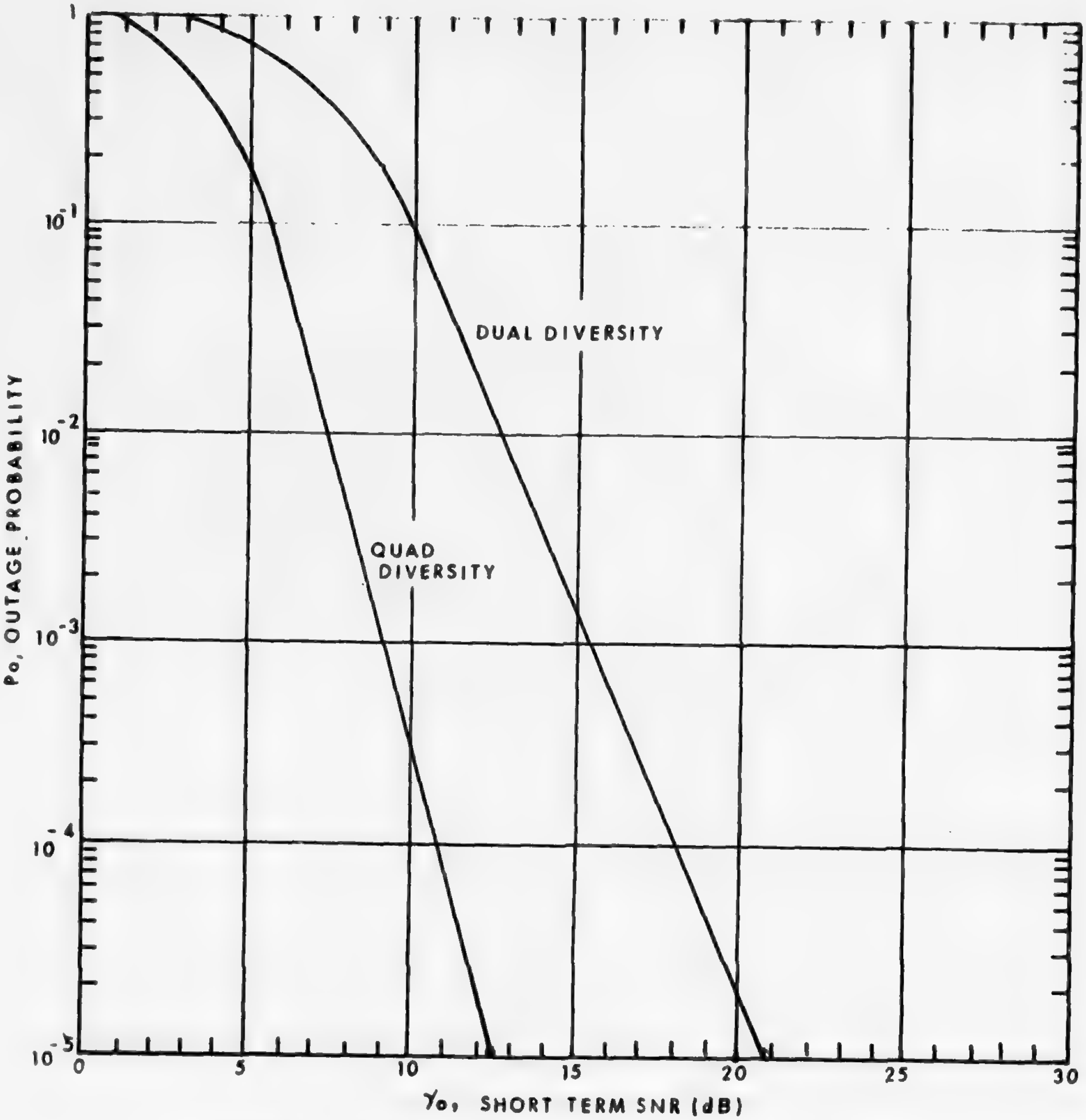


FIGURE 9. TROPOSCATTER RF LINK OUTAGE PROBABILITY

$$\eta_o = 2.4mN\ell^{1/2}b \left(1 - b \cdot \frac{\sum_{R=2}^{m} \frac{\ell^{R-1}}{(R-1)!}}{1-b} \right) \quad (\text{sec}^{-1}) \tag{14}$$

where ℓ, b and m are as defined previously and N is defined as the mean channel fade rate in Hz. Thus the Mean-Time-Between-Fade Outage (MTBFO) for troposcatter can be expressed as $\frac{1}{\eta_o}$.

Further, knowing MTBFO and P_o, the mean duration of an outage, t_o can be expressed as

- Mean Outage Duration

$$t_o = P_o \cdot \text{MTBFO}. \tag{15}$$

The distribution of fades relative to the mean can be determined from assumptions of a narrow band Rayleigh process and expressed in [10] as

$$P(t) = \frac{2}{u} I_1 \left(\frac{2}{\pi u^2}\right) \cdot \exp\left(-\frac{2}{\pi u^2}\right) \tag{16}$$

where $u = t/t_o$, I_1 is the modified Bessel function of the first order and P(t) is the probability that an outage will have a duration of t seconds or less. Figures 10, 11 and 12 illustrate the relationship of η_o, t_o, and P(t) to γ_o.

As discussed in Section IV,3,d, the Mean-Time-Between-Fade Outages (MTBFO) with duration $t_1 \leq t \leq t_2$ can be obtained by

$$\text{MTBFO}(t_1, t_2) = \frac{\text{MTBFO}}{P(t_2) - P(t_1)}. \tag{17}$$

The scaling of MTBFO (t_1, t_2) to give an estimate of the number of outages that will occur during a call-minute is given by Eq. 7.

The above discussion led to expressions for the relationship between γ_o and probability of fade outage per call-minute. This expression determines the short term $\overline{\text{SNR}}$ needed to meet the first two performance requirements of Table VI. Under certain conditions of γ_o and mean channel fade rate, the troposcatter channel will fade rapidly enough to cause several short fade outages per minute, hence the third and fourth requirements in Table VI. The probability that between two and five fade outages will occur during a minute and the probability that greater than five fade outages will occur during a minute can be obtained from (14) by determining the values of γ_o for which

$$\frac{2}{60} \leq \eta_o \leq \frac{5}{60} \text{ and } \eta_o > \frac{5}{60}. \tag{18}$$

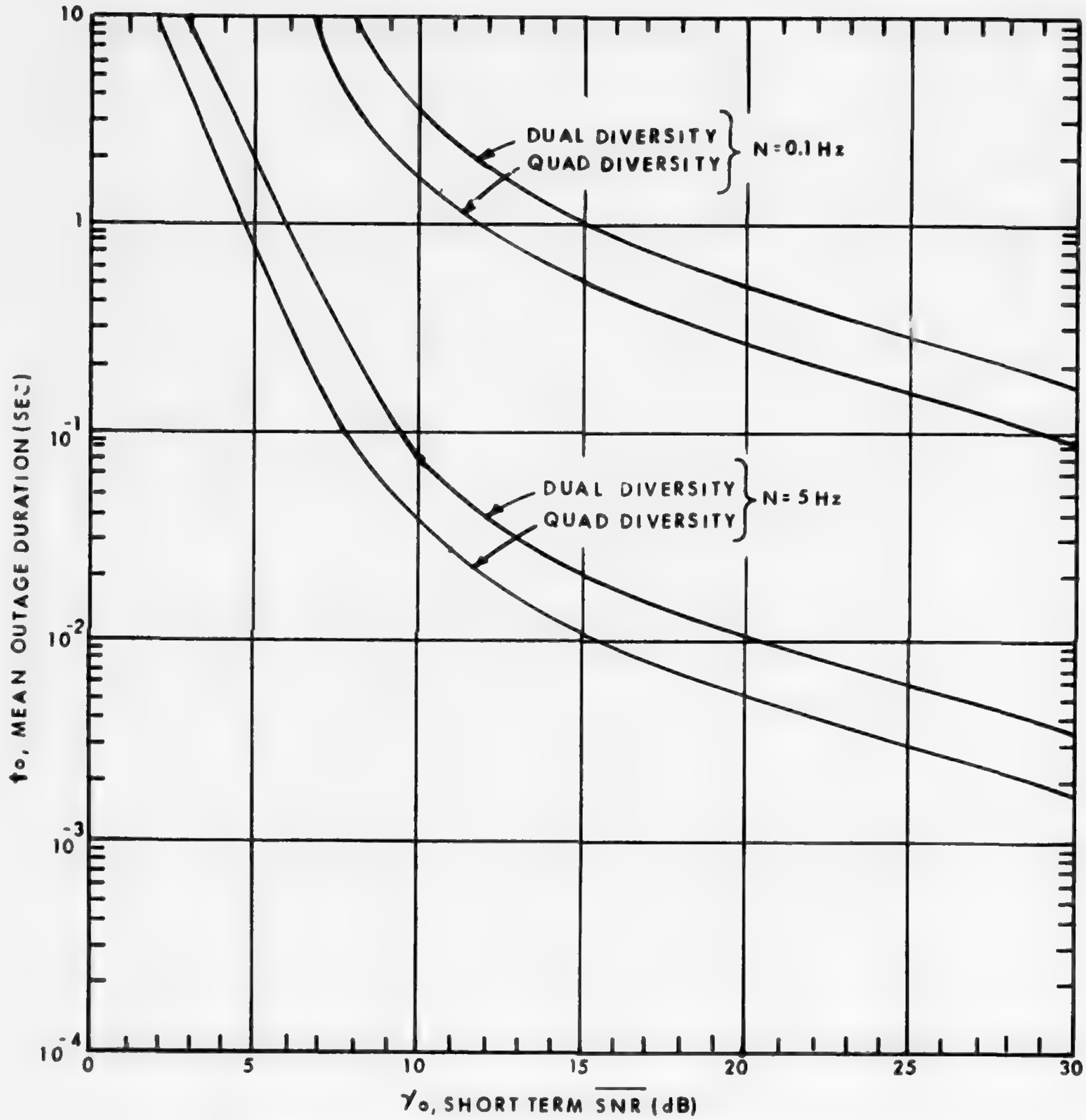


FIGURE 10. TROPOSCATTER LINK OUTAGE DURATION

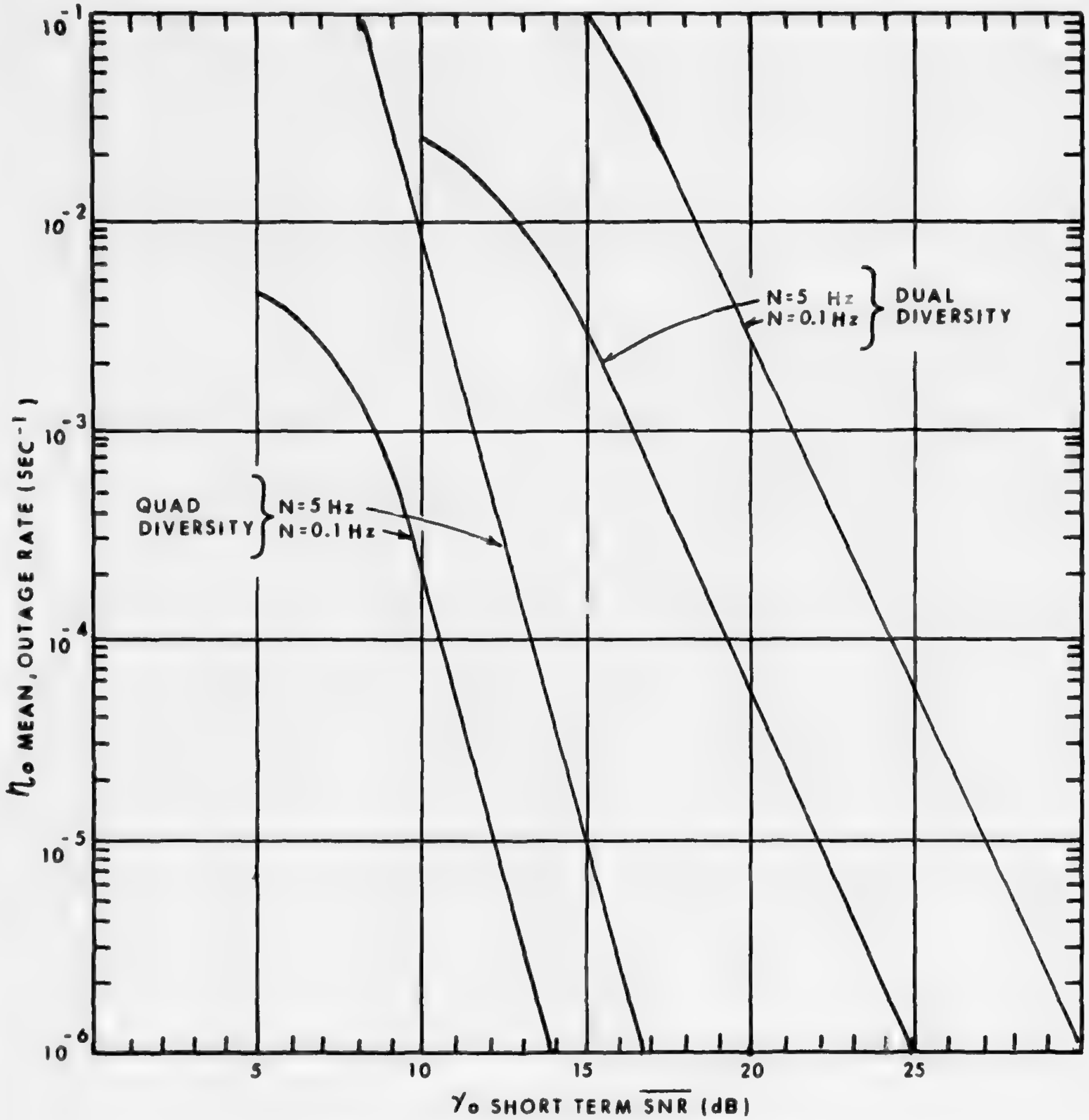


FIGURE 11. TROPOSCATTER LINK OUTAGE RATE

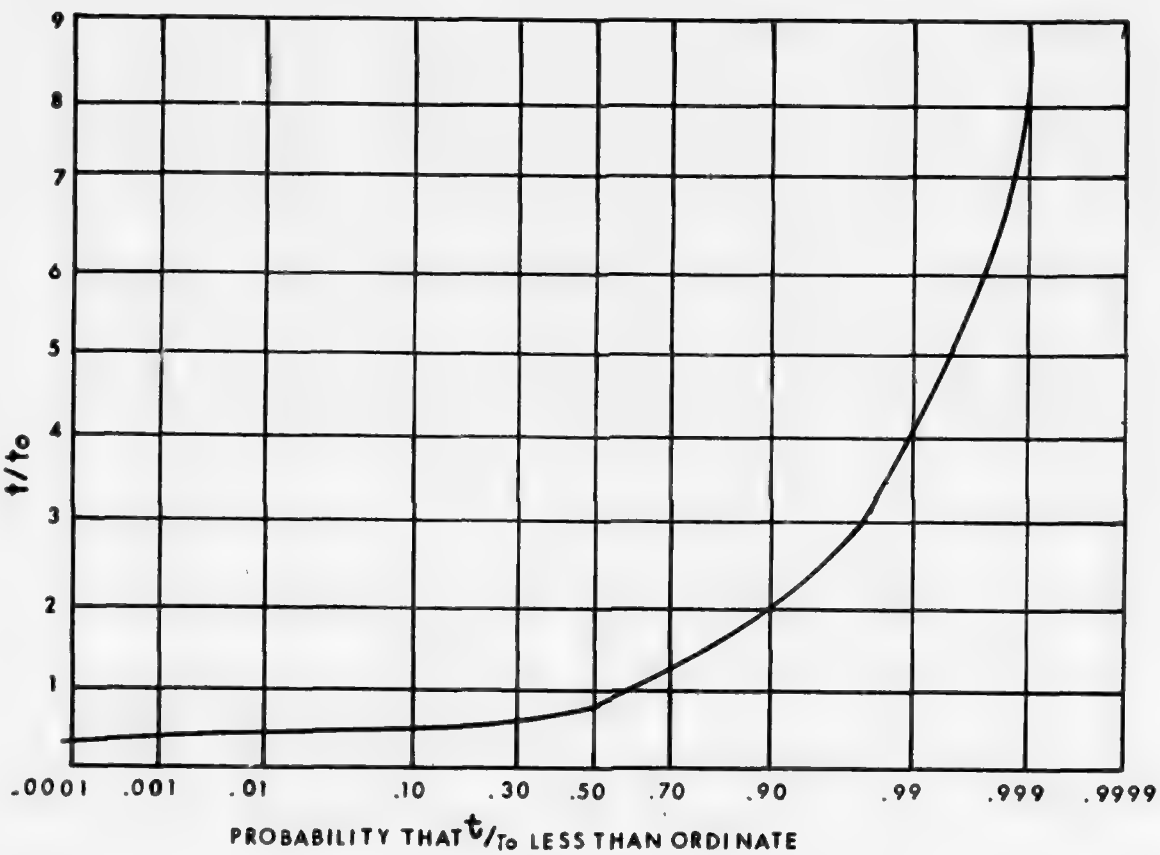


FIGURE 12. DISTRIBUTION OF TROPOSCATTER LINK OUTAGE DURATION

The preceding paragraphs have described expressions relating the probability of the various outage ranges tabulated in Table VI to a particular value of γ_0. Since this γ_0 is in itself a time varying parameter, it is characterized by a probability distribution and is normally expressed as a time availability. The total probability of occurrence of a particular outage range from Table VI is estimated by the probability of attaining a particular γ_0 or worse multiplied by the probability of outage occurrence given γ_0. Since the latter probability is a steep function of γ_0 (see Figure 11), the probability of outage occurrence during a typical call holding time goes rapidly from a very low value to a value near unity over a small range of γ_0. Thus, it is assumed that the most likely occurrence of an outage during a call results from the channel γ_0 falling to the level where the probability of outage occurrence given that level of γ_0 is very nearly unity. Based on this assumption, values of γ_0 have been chosen, for each of the outage ranges of Table VI, which result in a near-unity probability of occurrence for that outage range during a nominal call holding time (5 minutes). These values of γ_0 are listed in Table VII. The corresponding time unavailability requirements (1 minus time availability) are then simply the outage probability requirements of Table VI. Table VII thus represents a set of candidate combinations of γ_0 and time unavailability, R, where each combination satisfies one of the requirement statements of Table VI. The overall requirements for each troposcatter transmission configuration will then be determined by considering the long-term distribution of γ_0 to find which of the candidate requirements of Table VII is the most demanding.

The distribution of long-term variation in the short term γ_0 is usually described as being log normal, i.e.,

$$P(\gamma_0) = \frac{1}{\sigma\sqrt{2\pi}} \exp- \frac{(10 \log \gamma_0 - 10 \log \gamma)^2}{2\sigma^2} \tag{19}$$

where $P(\gamma_0)$ is the distribution function of γ_0, γ_0 is as previously defined, γ is the long-term (i.e., yearly) $\overline{\text{SNR}}$ and σ is the standard deviation of γ_0 about γ. Typical DCS paths exhibit standard deviations between 3 and 6 dB. Figure 13 illustrates the short term γ_0 distribution calculated from measured data for a typical medium distance DCS troposcatter link with σ= 5.6 dB [11].

Based on observations of the slope of the long-term γ_0 distribution, as evidenced in this figure and the candidate γ_0 values tabulated in Table VII, it is obvious that the most stringent long-term requirements are represented by the Range V outage requirement in C-Band and either the Range II or Range III requirement in L-Band, depending on the value of σ for a particular L-Band path. The σ of each L-Band troposcatter path to be digitized should be calculated to determine whether that particular path should be designed to Range II or Range III requirements.

TABLE VII. CANDIDATE γ_0* REQUIREMENTS FOR DIGITAL TROPOSCATTER

BAND	DIVERSITY	γ_0 (DB) EXCEEDED ALL BUT R PCT OF TIME			
		R_{II} = .075	R_{III} = .0075	R_{IV} = .25	R_V = .01
L (790-960 MHZ) OR	DUAL	12	6	8	N/A
S (1.7-2.4 GHZ)	QUAD	10	5	4	N/A
C (4.4-5.0 GHZ)	DUAL	7	3	16	15
	QUAD	5	N/A	9	8

*(WITHOUT IMPLEMENTATION MARGIN)

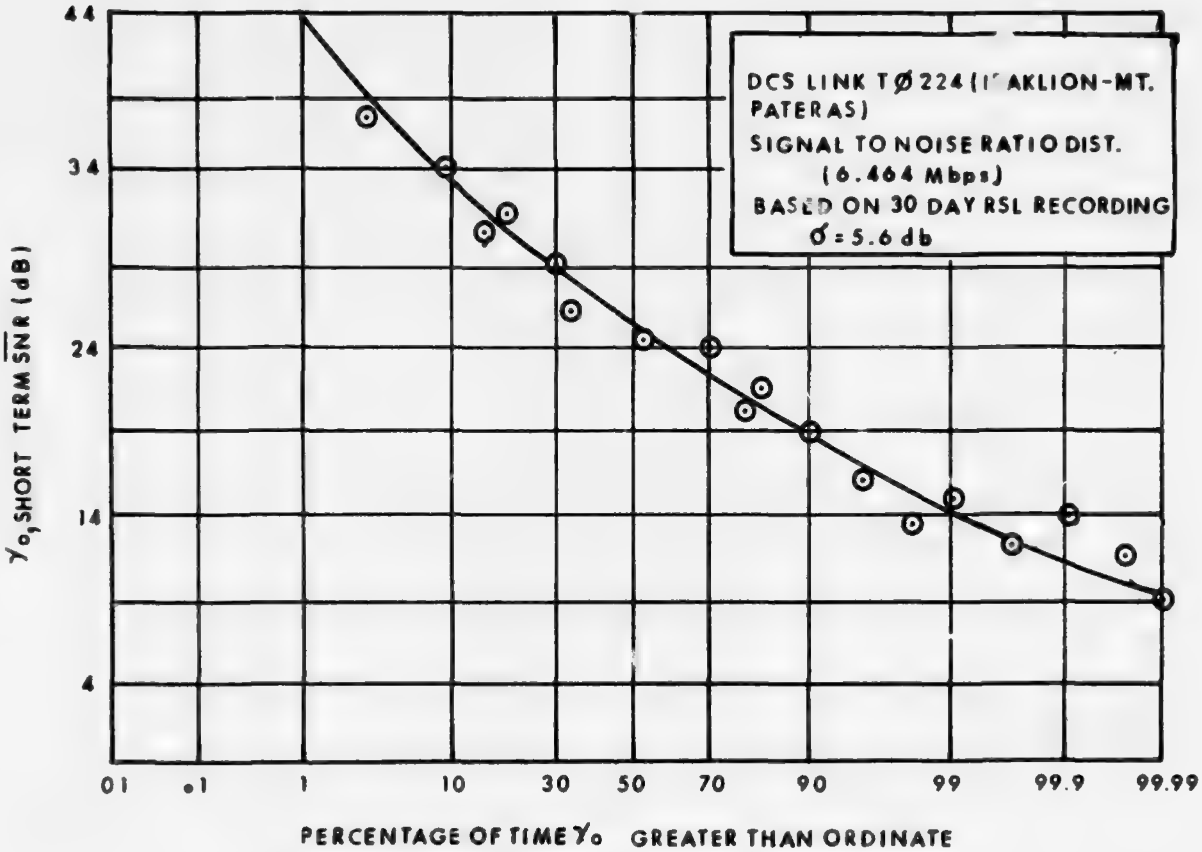


FIGURE 13. LONG TERM DISTRIBUTION OF γ_0 FOR A TYPICAL DCS TROPOSCATTER LINK

This subject will be extensively dealt with in [9]; however, as a general rule, for values of σ less than 6 dB, the most stringent design requirement is given by the Range II γ_0 and associated time unavailability requirement. For most DCS L-Band paths, it is expected that the long-term $\overline{SNR}$ requirements for Range II will dominate and therefore most DCS L-Band digital troposcatter links will be designed to satisfy Range II requirements. The resultant values of γ_0 and their associated time unavailabilities, selected from Table VII in accordance with this rationale, are presented in Table VIII. Design of DCS digital troposcatter links to the requirements tabulated in Table VIII should insure meeting the dominant outage probabilities and exceeding all others.

The γ_0 requirement specified in Table VIII for L-Band links is nearly the same for dual and quad diversity while, at C-Band, a significant diversity advantage is apparent. This apparently contradicts the normal expectation that increased diversity will always significantly reduce the required γ_0. Nevertheless the γ_0 values are correct. This conclusion stems from choosing the most demanding link design criteria by setting the probability of occurrence of each of the outage ranges of Table VI near unity. The resultant γ_0's thereby derived were paired with their associated outage probabilities (as shown in Table VII). Then the γ_0 and associated outage probability pairs are compared to each other to determine which of the pairs will demand the highest transmitted power from a time availability viewpoint. The most demanding of these pairs are then listed in Table VIII and represent the most demanding link design requirements. Meeting of these requirements for a particular L or C-Band path should assure that the experienced outage probabilities associated with all outage ranges are less than or equal to that specified in Table VI. Although this conclusion apparently obviates the need for quad diversity on L-Band troposcatter links, the additional diversity is still frequently required to reduce the expected range of multipath spread and to provide sufficient equipment redundancy to meet equipment-related availability requirements.

The derivation of troposcatter link design criteria related above is based on the assumption that DPSK modulation is used. To remove this dependence on modulation technique and provide a translation to other digital modulation techniques, we will use a factor Γ which represents the ratio in dB between the non-fading $\overline{SNR}$ of DPSK at a BER of 10^{-4} and the non-fading $\overline{SNR}$ corresponding to a 10^{-4} BER for the alternate technique. This factor, Γ, represents the incremental margin which must be applied to the link in order to assure the same performance.

$$\text{i.e.,} \quad \gamma_0^A = \gamma_0 + \Gamma \text{ (dB)} \tag{20}$$

where γ_0^A = $\overline{SNR}$ requirement of an alternate modulation technique (dB)

γ_0 = $\overline{SNR}$ requirements of Table VIII (dB)

Γ = Ratio between 10^{-4} BER points for DPSK and the alternate modulation technique (dB)

TABLE VIII. γ_0 REQUIREMENTS FOR DIGITAL TROPOSCATTER

BAND	DIVERSITY	γ_0 (dB)*	EXCEEDED ALL BUT R_0 PCT OF TIME
L,S	DUAL	12	.075
	QUAD	10	.075
C	DUAL	15	.01
	QUAD	8	.01

(* WITHOUT IMPLEMENTATION MARGIN)

On links with little dispersion (e.g., short diffraction paths) where the maintenance of at least dual implicit diversity during periods of high long-term path loss is doubtful, alternate performance criteria are required. These links should be implemented in quad diversity and will require a value of γ_0 that is 3 dB less than that specified in Table VIII for dual diversity since no implicit diversity gain will be achieved but there will also be no inband diversity power sharing.

The global reference circuit described in Section II, 1 contains only one troposcatter link for each 600-mile (965 km) channel. In certain geographical regions, tandem troposcatter links may be used to bridge between widely dispersed forces. It is thus of interest to consider the expected performance of a tandem troposcatter connection and, specifically, whether such a tandem connection is expected to degrade channel performance below system margins. In digital transmission using PCM, channel performance exhibits a strong threshold characteristic such that the measure of channel performance is essentially the percentage of time below threshold. Therefore, the effect of tandeming two links is, at worst, the linear addition of their times below threshold. Since the average link requirements were initially allocated on a mileage basis, the tandeming of two troposcatter links, each of which meets average system performance requirements, results in a composite channel which also meets average requirements. The short term performance of two tandem channels, during a period with fading frequency that is greater than the mean, may be an even greater departure from specified mean values than either of the individual channels due to link-to-link correlation, but even in this case, unless the fade margin and the γ_0 of the two channels is identical, the poorer of the two channels on a short term basis will dominate short term performance. Thus, it is not expected to be necessary to limit the tandeming of properly engineered digital troposcatter links.

h. System Gain - Troposcatter. A descriptive indicator of transmission system efficiency is system gain. As described in Section IV,3,e for line-of-sight (LOS) links, system gain is the difference (in dB) between the power output of the transmitter, as present at the antenna feed line(s) and the sensitivity of a diversity receiver referred to its interface with the antenna feeder. For troposcatter links, receiver sensitivity is that average received signal level ($\overline{RSL}$) required to meet the γ_0 requirements specified in Table VIII.

However, unlike LOS, digitization of troposcatter will occur primarily through the application of a troposcatter modem [7] with little attention given to RF equipment optimization beyond present levels. Thus the utility of the system gain concept for troposcatter is related to estimates of the maximum data rate than can be accommodated over a particular troposcatter link. Following a definition of system gain as related to troposcatter, estimates of achievable traffic cross-section (in Mb/s) for typical DCS troposcatter links will be developed from existing DCS troposcatter link data.

For a C or L-Band troposcatter path, the required system gain can be expressed parametrically as

$$G_s = G\,(L_{BPL}, L_w, L_{tp}, S_t, G_{at}, G_{ar}, L_{am}) \qquad (21)$$

where

L_{BPL} = Basic Path Loss as defined in [7] (dB)

L_w = total waveguide loss (dB)

L_{tp} = power loss due to signal processing at the transmitter (e.g., time-gating, or filtering for broad banding)

S_t = γ_0 requirement from Table VIII (dB)

G_{at}, G_{ar} = transmitting and receiving antenna gain, respectively (dB)

L_{am} = aperture to medium coupling loss as defined in [7] (dB).

As discussed in [9], the calculation of L_s is specified at a service probability of .95. Since both L_s and possibly L_{am} are time variant, the system gain requirement for a particular configuration is

$$G_s = L_{fs} + L_s\,(.95, R) + S_t + L_w + L_m + L_{tp} - (G_{at} + G_{ar} - L_{am})\ (\text{db}) \qquad (22)$$

where L_s (.95, R) represents the scatter loss not exceeded more than (100-R) percent of the time computed at a service probability of .95, where R is the time unavailability specified in Table VIII. Modification of G_s to account for measured path loss data, where available, will be accomplished in the manner specified in [12] to aid in the engineering of specific links.

A selection of 20 DCS troposcatter links within the European/Mediterranean area was used to develop estimates of the available system gain on each of these links at each of the data rates of interest (i.e., nominally 6, 9 and 12 Mb/s). This calculation made use of available link/RF equipment data, assumed a 4 dB implementation margin for the digital tropo modem, PSK modulation and used calculated path losses. Additionally, broadbanding of high power amplifiers results in a reduction of available power output. This reduction has been assumed to be 2 dB at 9 Mb/s and 6 dB at 12 Mb/s. Estimates were also made of the system gain required for quad diversity operation for each of these links at each data rate of interest based on the required short term $\overline{\text{SNRs}}$ tabulated in Table VIII. An estimate was made of whether each particular link has sufficient multipath dispersion to allow characterization as effective eighth order or whether a flat fading

representation was appropriate (as treated in Section IV,3,g). From these estimates, a parameter called excess system gain was calculated for each link which represents the difference, in dB, between available and required system gains at 3, 6 and 12 Mb/s (nominal). Figure 14 is a cumulative distribution of the excess system gain, E, for each data rate.

Clearly, all links in Figure 14 with positive excess system gain are suitable for the applicable data rate. A 5 dB increase in system gain is considered to be practical and economical for many links (e.g., through RF equipment upgrade or increased diversity). Thus, those links in Figure 15 with excess system gain between 0 and -5 dB are also considered to be candidates for the applicable data rates.

For links with values of E between -5 dB and -8 dB, system gain improvements would result in available system gains within 3 dB of that necessary to meet the performance requirements developed herein. These links are likely to provide a grade of service acceptably close to "standard systems" with the most apparent indication of their "substandardness" evidenced by a greater cumulative outage probability, the increase being typically confined to late afternoon periods of 1-3 hours where the channel will be perceived as annoying but talkable. In general, links with values of E more than 8 dB below the required value should be evaluated for re-siting or, if feasible, replacement by other transmission media. (However, links in the latter category are normally already substandard. Due to the implicit diversity advantage of digital troposcatter coupled with the threshold behavior of PCM, digitization of troposcatter links should always result in perceived channel quality superior to that of the replaced analog channels).

From Figure 14, at 6 Mb/s, approximately 50% of all links have positive excess system gain, another 10% have excess system gain greater than -5 dB and 70% have excess system gain greater than -8 dB. At 12 Mb/s, the corresponding percentages are 25%, 40% and 50%, respectively. The criteria for Figure 14 were developed from the fade margin considerations of Section IV,3,g. It is considered likely that experience and testing will lead to a minor moderation of these fade margin estimates which will allow the inclusion of greater percentages of links in the region of acceptable excess system gain. However, host country frequency allocation limitations constitute another important bit rate limitation on troposcatter links. It is felt that a transmission rate of 6 Mb/s (nominal) should be considered the normal capacity of DCS troposcatter links with exceptions being possible where both the link design and suitable frequency allocations are available.

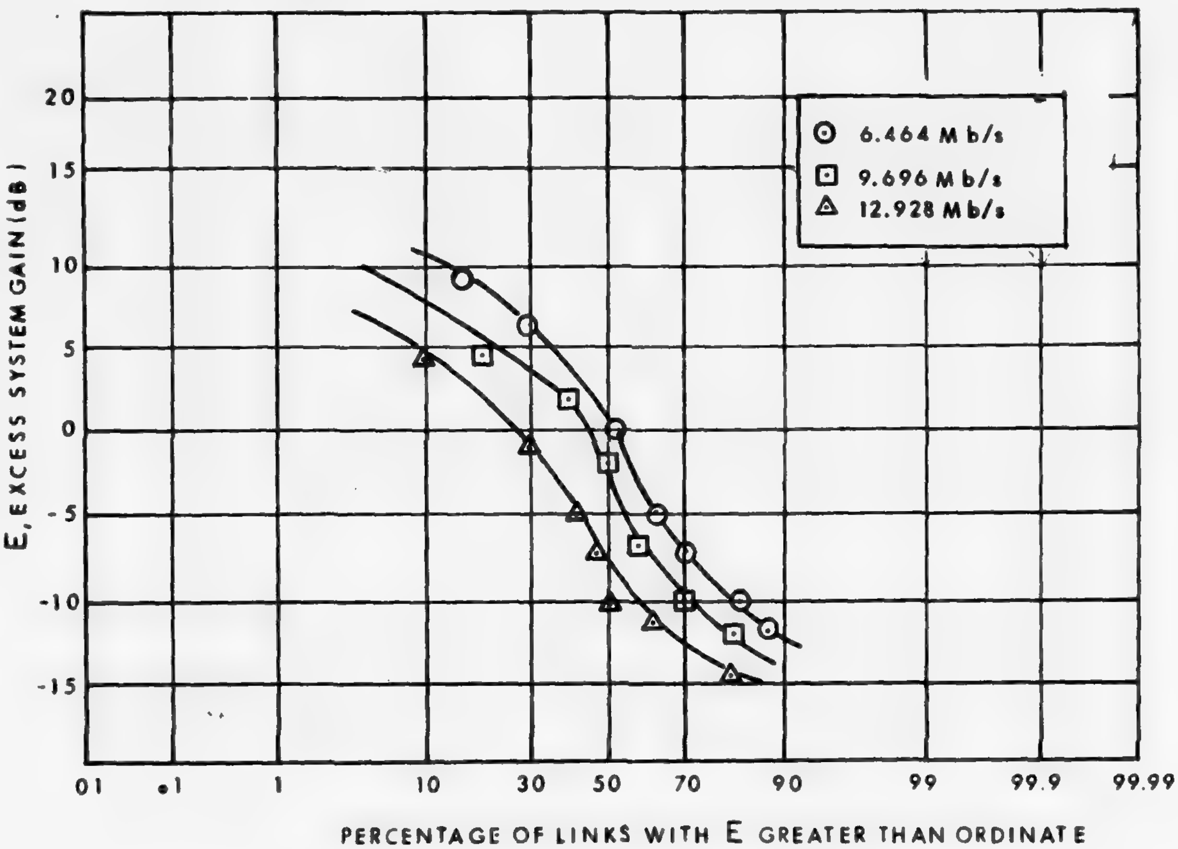


FIGURE 14. DISTRIBUTION OF TROPOSCATTER LINK EXCESS SYSTEM GAIN

i. Error-Free Blocks - Troposcatter. The concept of error-free blocks attempts to provide a data customer with an indication of transmission quality which relates to the efficiency of his data system. The specified requirement for the probability of receiving a 1000-bit data block in error for the reference troposcatter hop is $2.5 \cdot 10^{-4}$. As discussed in Section IV,3,f, the probability of receiving a data block of n bits duration with at least one error is very nearly given by the probability that the bit error rate is 1/n or worse. Thus, from equation (13)

$$P(BE|\gamma_0) \cong 1-b_\beta \cdot \sum_{R=1}^{m} \frac{\ell_\beta^{R-1}}{(R-1)!} \qquad (23)$$

where $P(BE|\gamma_0)$ = Probability of receiving a block in error given a short term $\overline{SNR}$, γ_0

$$b_\beta = \left(\frac{2}{n}\right)^{2/\gamma_0}$$

$$\ell_\beta = -\ln b_\beta$$

$$m = \begin{matrix} 4, \text{ dual diversity} \\ 8, \text{ quad diversity} \end{matrix}.$$

Since γ_0 is a time varying parameter, it is characterized by a probability distribution and normally expressed as a time availability. The total probability of occurrence of an error block is determined by the probability of attaining a particular γ_0 or worse multiplied by the probability of outage occurrence given γ_0. Since the latter probability is a steep function of γ_0 (see Figure 15), the probability of an error block goes rapidly from a very low value to a value near unity over a small range of γ_0. Thus, it is assumed that the most likely occurrence of a block error results from the channel γ_0 falling to the level where the probability of outage occurrence given that level of γ_0 is very nearly unity.

i.e., $P(BE) \cong P(BE|\gamma_0)P(\gamma_0)$ (24)

where $P(BE|\gamma_0) \cong 1$.

For a typical block of 10^3 bits, Figure 15 illustrates the distribution of block error probability given γ_0 as a function of γ_0. Note that, just as with line-of-sight, the $\overline{SNR}$ unavailability requirements developed earlier for voice channel performance will assure a significantly greater overall error-free block probability than the required $2.5 \cdot 10^{-4}$. Thus, as with line-of-sight links, the fade-margin requirements for voice channels are more demanding than those for data channels.

j. Bit Count Integrity and Loss of Frame Synchronization. Section IV,3,b stated the requirements that not more than one in ten line-of-

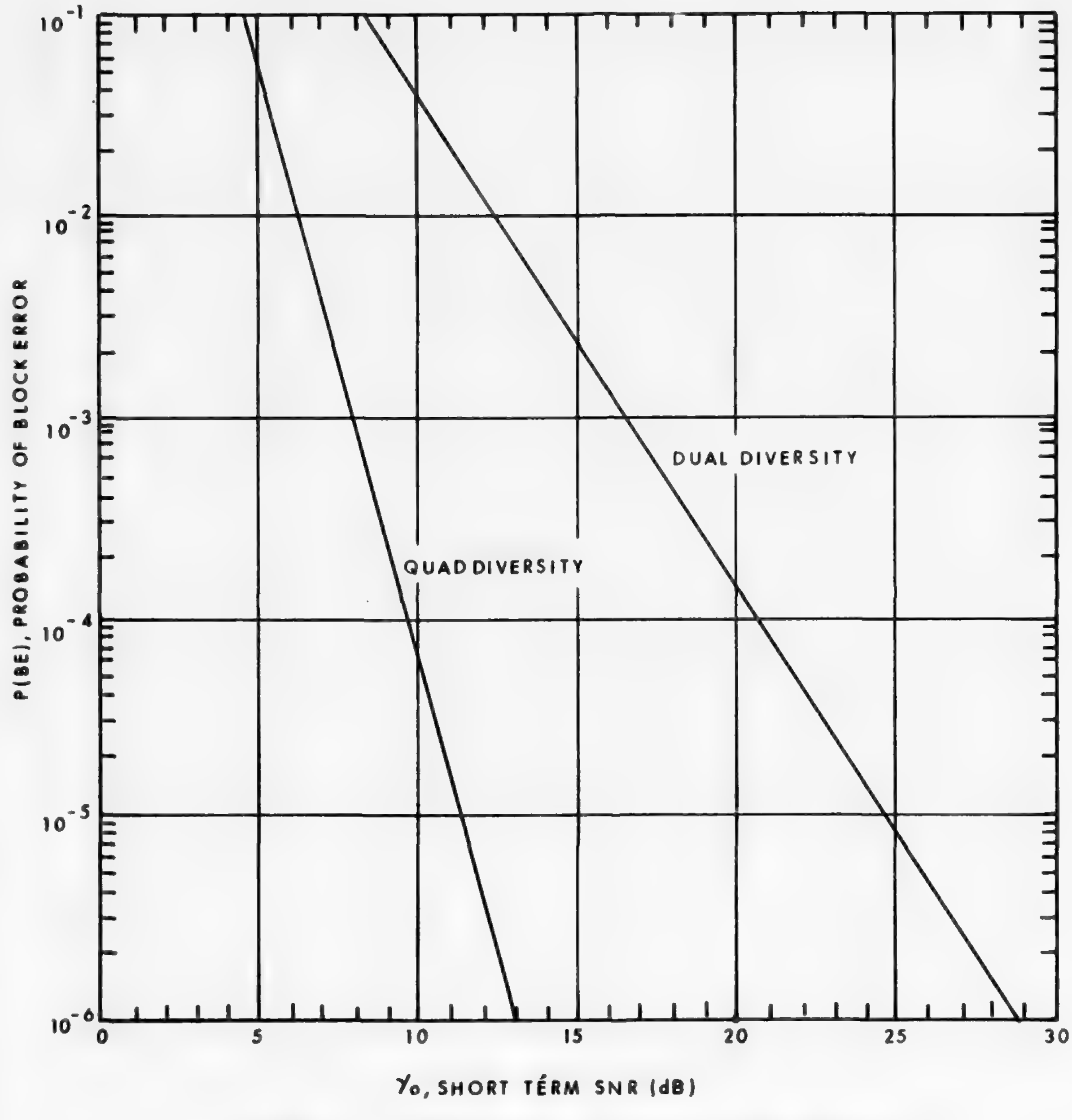


FIGURE 15. TROPOSCATTER LINK BLOCK ERROR PROBABILITY

sight fades nor one in a hundred troposcatter fades result in a loss of BCI. Losses of bit count integrity (BCI) may occur due to one of the following four causes:

(1) Loss of phase lock in receiver bit timing recovery loops. When the received signal undergoes a deep fade, the recovery loops become noisy. At some depth of fade which is a function of these loop bandwidths, the carrier recovery loop will break lock and the receiver timing output signal will drift away from the correct frequency. When this drift is sufficient to insert an extra timing pulse, or delete a timing pulse from the receiver timing output, bit count integrity of the data stream is lost because the recovered timing signal is used to sample the data stream, creating an extra bit or deleting a bit when an extra pulse or a loss of pulse occurs on the timing line. The frequency of such occurrences can be minimized by designing sufficiently narrow carrier and timing recovery loop bandwidth, and by implementing the timing loop with memory (2nd order loop) so that it does not quickly drift in frequency when the input signal is lost. A typical receiver will hold timing recovery lock down to 15-20 dB below the signal level corresponding to 10^{-4} bit error probability. From Section IV,3,d, equation (6), the mean-time-between-fade outage for LOS links is given by

$$MTBFO = k \cdot 10^{0.15F} \tag{25}$$

where k is a constant for a given RF path and F is the fade depth in dB. Thus, for a 10^{-4} outage threshold and a receiver which will hold lock 15 dB below this threshold, the fraction of total LOS outages which will incur a loss of BCI due to timing recovery loss is

$$\frac{k \cdot 10^{-0.15F}}{k \cdot 10^{-0.15(F+15)}} = \frac{1}{10^{0.15x15}} = .006 \text{ or } 0.6\% .$$

For troposcatter fades, the troposcatter modem typically uses highly stable oscillators which will retain BCI through a moderate length fade, independent of fade depth. Thus, the expected fraction of troposcatter fades in which BCI is lost due to bit timing clock slips is trivial.

(2) Transmission errors in asynchronous multiplexer pulse stuffing control words. The DCS digital transmission system will be initially implemented with asynchronous pulse-stuffing 2nd-level multiplexers to accommodate unsynchronized 1.544 Mb/s data streams. These multiplexers transmit control words from the multiplexer to the demultiplexer to indicate whether or not a bit has been stuffed. If an error occurs in the transmission of one of these words, the demultiplexer will incorrectly add or delete a bit

from the data stream, hence causing a loss of bit count integrity. The percentage of fade outages in which BCI is lost due to the stuff control word errors is determined by the coding redundancy of the control word. It is desired to estimate the percentage of fade outages in which one or more stuff code errors occurs. The normal information available to describe a fading channel is its distribution function which describes the percentage of time that the received signal is at or below a given level. It is possible, with this information, using the methods of reference [6] to calculate the mean time between stuff word errors. In order to determine how these stuff word errors are grouped during fades, further manipulation is necessary. From [6], the mean probability of stuff word error is given by

$$\overline{P(SWE)} = \sum_{x=\frac{n+1}{2}}^{n} \int_{0}^{0.5} \binom{n}{x} p^{x} \quad (1)^{n-x} p(p)dp \qquad (26)$$

where n = the length of the stuff control word
p = probability of bit error
p(p) = probability density function of p derived from the fading channel model.

Using equation (26) it is possible to obtain the total expected probability of stuff word error for a given fade margin. The mean time between stuff word error is given by

$$MTBSWE = \frac{1}{Rs \cdot \overline{P(SWE)}} \quad (sec) \qquad (27)$$

where Rs = the stuff rate in Hz.

To determine how these errors are distributed in fades, the conditional probability of stuff word errors, given a fade to a given level or below is calculated from

$$\overline{P(SWE/F)} = \frac{\overline{P(SWE)}}{P(F)} \quad P(SWE/F) = \frac{\overline{P(SWE)}}{P(F)} \qquad (28)$$

where $\overline{P(SWE/F)}$ = the mean probability of a stuff word error given a fade of F dB or greater
P(F) = probability of a fade of F dB or greater
= (P_0 from Section IV,3,d, equation (1)).

The expected number of errors per fade can now be obtained from

$$E(SWE/fade) - \overline{P(SWE/F)} \times R_S \times t_0 \tag{29}$$

where $\overline{P(SWE/F)}$ and R_S are as previously defined and t_0 is obtained from Section IV,3,d, equation (3). For a period, T, the total number of stuff word errors which occur for any given level of fade can be computed from

$$N_F = \frac{T}{MTBFO} \times E(SWE/fade) \tag{30}$$

where N_F = number of stuff word errors occurring during fades of depth F or below during the time T. Table IX summarizes the expected number of stuff word errors on a dual diversity LOS channel with 32 dB fade margin as a function of fade depth for a 9-bit stuff control word and a 2700 stuff per second stuff rate during a 10^9 second period.

TABLE IX. STUFF WORD ERRORS AS A FUNCTION OF FADE DEPTH

Fade Depth	No. of Fades in Period	E(SWE/fade)	No. Stuff Word Error in Period in Fades at F or below
32	625	4.37	2730
35	227	12	2724
40	40	68	2720
45	7	385	2695
50	1	1900	1900

Table IX shows that all but about 35 errors out of a total of 2730 occur during the 7 fades below 45 dB. Most of the remaining errors occur during the 33 fades below 40 dB but not below 45 dB. Thus, of the 625 outages, at worst, about 42 of these, or 6.7% cause a stuff word error for a 9-bit code. Based on this result, a 9-bit stuff code is required to meet the 10% requirement stated at the beginning of this section.

Table IX and the resulting percentage of fades which experience loss of BCI are typical of line-of-sight links. For troposcatter links, the percentage of all fade outages (below 10^{-4} bit error probability) which fall an additional 8 dB below the fade outage threshold (e.g., the 40 dB fades in Table IX) is smaller than that percentage for line-of-sight channels since the additional diversity of the tropo-

scatter channel flattens the fading distribution. In addition, the length of troposcatter fades decreases much more rapidly as fade depth increases than does the LOS fade length. This is also due to the higher order of diversity. Thus, the percentage of all troposcatter fade outages which experience a loss of BCI is much smaller than for LOS.

(3) Unnecessary resynchronization searches by multiplexers. Time division multiplexers transmit a frame code in every frame to maintain the demultiplexer in synchronism with its corresponding multiplexer. A frame detection circuit is used to find and lock to this frame code. The detection circuitry makes an "in-frame/out-of-frame" decision based on the ratio of correct to incorrect frame bits received in a unit of time, on the assumption that such a high error rate must have been caused by incorrect frame alignment. When a high rate of transmission error occurs, the frame detection circuitry may conclude that frame synchronization has been lost when, in fact, it has not. Most multiplexers impose a fairly stringent criterion on how they reach the conclusion that frame sync has been lost, but when this conclusion is reached, they undertake a frame search. The frame search involves sequentially stepping through each bit position in the frame, testing to see whether the data in that position meets the frame code criterion. Such a search will cause a loss of bit count integrity even if the loss of BCI did not previously exist. Since an actual loss of frame is preceded by a loss of BCI, both of which are simultaneously corrected by resynchronization, and since the effect of a perceived loss of frame in a high error environment is to precipitate a loss of BCI, the specification of a mean time to loss of frame synchronization should be handled as a part of the specification for BCI.

The frame sync code is perturbed by the same mechanism as the stuff code described in the preceding section. The probability of a declaration of out-of-sync, for equal frame and stuff code word error probabilities is related by

$$\frac{P(OOF)}{P(SWE)} = \frac{R_F}{R_S} \qquad (31)$$

where P(OOF) is the probability of an out-of-frame declaration and R_F and R_S are the frame and stuff rates, respectively. Thus, for an out-of-frame probability equal to the probability of stuff code error, the frame code must result

in a word error probability that is R_F/R_S higher than the stuff code word error probability. A typical value of R_F/R_S for a Level 2 TDM multiplexer is 10 and for a Level 1 PCM multiplexer is 1 (i.e., the ratio of R_F for the Level 1 PCM multiplexer to R_S for the Level 2 TDM multiplexer). Thus, the Level 1 PCM multiplexer should use a frame code criterion equal to the 9-bit stuff code criterion, i.e., 5 or more erroneous bits out of 9 transmitted bits for OOF declaration. The Level 2 TDM multiplexer should use a criterion resulting in a frame code word error probability approximately 10 times more stringent than the above, for example 4 or less erroneous bits out of 9 transmitted bits.

(4) Switching between unsynchronized redundant units. Redundancy is required in many equipments of the digital transmission system to provide the required level of system availability. Switching between redundant units may occur due to failures or may be manually initiated as a fault isolation technique. If redundancy is not implemented with mutually coordinated framing, such switching will introduce a loss of bit count integrity. Frame and bit synchronization between parallel redundant equipment is required in DCS systems. This not only prevents loss of BCI when equipment fails but it also allows tech control personnel to manually switch between redundant equipments during fault isolation procedures without causing loss of BCI.

k. Transmitted RF Bandwidth. Frequency assignments in the overseas DCS depend on the approval of host nation frequency allocation boards. Such approval extends not only to the assignment of a specific authorized band but also to the amount of incidentally radiated power which falls outside the band. Currently, most DCS frequency allocations require that 99% of a transmitter's radiated emission fall within the assigned bandwidth. No firm rules for out-of-band radiation for digital systems have yet been developed in CCIR deliberations or in any similar international forum. DCS equipments must be built to a standard which will be accepted by all host nations. The FCC has formulated a rule for US domestic digital applications [13]. This rule is specified in the current System Specification (Appendix A) for line-of-sight radio equipment and the AN/FRC-163 U.S. Army Project Digital Radio and Multiplex Acquisition (DRAMA) Procurement radio specification.

The FCC Docket 19311 rule imposes the need for a relatively complex transmitter implementation, requiring either a very high-Q RF filter or a very linear power amplifier in order to meet both the power output and RF bandwidth requirements. This requirement has greater impact on intended government applications than on most commercial applications since the government requirements are for narrower total authorized bandwidth, hence higher required filter Q. In view of the absence of firm foreign government emission standards for digital systems, the FCC

Docket 19311 requirement for DCS systems should be considered tentative until testing of the AN/FRC-163 DRAMA radio has clarified the potential cost and risk impact of the Docket 19311 requirement on DCS equipment.

For troposcatter equipments, RF signal structures are required which are adapted to channel dispersion. The current state-of-the-art for such signal structures prohibits meeting the FCC Docket 19311 requirement by a significant margin. In addition, the required radiated power on troposcatter links makes the necessary methods of spectrum conservation at troposcatter sites somewhat different than those of line-of-sight. The troposcatter transmitter power output is high enough in most cases, so that receiver selectivity is not sufficient to allow adjacent channel use even if no power is radiated outside the assigned band (i.e., the legally radiating carrier signal would be insufficiently attenuated by receiver selectivity on the adjacent channel). Thus, it is customary to specify radiated power in the adjacent channels for troposcatter transmission in terms of the 99% power bandwidth, as contained in the System Specification, and to specify ultimate attenuation requirements (i.e., far from the carrier) in terms of the MIL-STD-461 requirement.

1. Multiplexer Output Phase Slewing. The output clock rate of an asynchronous multiplexer contains short term variations due to the timing discontinuity occurring when a stuffed pulse is deleted. These variations are minimized by a low pass filter in the demultiplexer clock recovery loop which smooths the effect of the discontinuity over many bits. The combined effect of this periodic destuffing and subsequent smoothing results in an output timing rate which oscillates above and below the average rate with an average period equal to the average stuff rate. During periods when the instantaneous frequency is above the long-term average, the phase of the output clock monotonically increases relative to the phase of a stable clock at the average rate. Similarly, when the instantaneous frequency is below the average, the relative phase monotonically decreases. These phase ramps, if excessive, present a problem to the phase lock timing recovery loops of interfacing equipments. If the output signal phase ramp rate exceeds the loop response rate continuously for a period long enough to accumulate a 90° phase difference, the timing recovery loop will break lock. The measure of such phase slewing is the peak relative phase excursion (i.e., change in phase difference between the fluctuating output signal and a stable reference signal) that occurs over a specified period of time. The values for this parameter specified in the System Specification (Appendix A) were obtained from preliminary testing performed at RADC on typical timing recovery bandwidths. DCEC is currently embarking on a detailed study effort to validate these preliminary specification values and to develop equipment cost sensitivity data on this parameter.

V. FUTURE STUDY ACTIVITIES

Future study activities during the next year are expected to address the definition of the detailed parameters of the Transmission Status Monitoring and Control Subsystem (see the System Specification, paragraph 3.1.1.3.10). This study will determine the necessary connectivity of data flow for status monitoring and remote control purposes, the required framing and bit rate allocations for the telemetry channel, the method of passing necessary data through intermediate stations, and requirements for subsystem response time.

Another area of study is the specific buffering, submultiplexing, modems, timing distribution and patch and test capabilities needed to implement the 16 Kb/s transmission needed in the DCS transmission plant for the AUTOSEVOCOM II Network. This study will consider problems associated with a mixed media plant composed of DCS terrestrial digital channels, DSCS digital channels, DCS analog channels and leased commercial channels.

Verifications of the design criteria for digital troposcatter links will be addressed via system testing of various user services. Based on this effort, further refinement of the design criteria contained herein may occur along with the development of implementation guidelines for DCS digital troposcatter transmission facilities.

Specific recommendations regarding the implementation of synchronous network timing control are expected to be developed in the coming year. Also, the desirability of implementing coordinated resynchronization control among multiplexers in dispersed locations will be addressed.

Concepts have been advanced for implementing remotely controlled channel patching via an electronic channel reassignment unit. The applicability and desirability of such a concept for DCS applications will be studied.

Specifications will be developed for the accumulation of phase jitter (particularly phase slewing jitter) through multiple tandem connections.

REFERENCES

(1) RADC-TR-74-330, "Line-of-Sight Techniques Investigation," CNR, Inc., January, 1975, p. 2-41.

(2) A.P. Barsis, C.A. Samson, and D. Smith, "Microwave System Performance Studies Over Long Line-of-Sight Links," Institute for Telecommunications Sciences, International Conference on Communications, 1976, Vol III, p. 46-12.

(3) A. Vigants, "Space Diversity Engineering, BSTJ, Volume 54, No. 1, (January 1975) pp. 103-142.

(4) A. Vigants, "Number and Duration of Fades at 6 and 4 GHz, "BSTJ, Volume 50, No. 3, (March 1971) pp. 815-841.

(5) A. Vigants, "The Number of Fades and Their Durations on Microwave Line-of-Sight Links With and Without Space Diversity," 1969 International Conference on Communications Proceedings, Paper No. 69CP306-COM, NTC 75, Volume II, pp. 28-25 to 28-31.

(6) J.L. Osterholz, and D.R. Smith, "The Effects of Digital Tropo Error Statistics on Asynchronous Digital System Design," 1975 National Telecommunications Conference Proceedings, Volume II, pp. 28-25ff.

(7) "Transmission Loss Predictions for Tropospheric Communications Circuits," NBS Technical Note 101, (January 1967).

(8) CCIR Report 244-1, "Estimation of Tropospheric-Wave Transmission Loss," Volume II, (October 1966).

(9) TR 17-76, "Integration of Digital Troposcatter into the Defense Communications System," To be published.

(10) S.O. Rice, "Statistical Properties of a Sine Wave Plue Random Noise," BSTJ, Volume 27 (January 1948).

(11) ESD-TR-66-638, Final Test Report European Mediterranean Tropospheric Scatter Communications System-Phase IV, AF 19(626)-21, (December 1966).

(12) A.P. Barsis and K.A. Norton, et al., "Performance Predictions For Single Troposcatter Communications Links and For Several Links in Tandem," NBS Technical Note 102, (August 1961).

(13) FCC Docket No. 19311, (September 19, 1974).

APPENDIX A

DCS TERRESTRIAL DIGITAL TRANSMISSION SYSTEM SPECIFICATION

1.0 GENERAL

This specification is intended to document the configurations, functions and performance parameters of terrestrial digital DCS transmission facilities. Its purpose is to provide guidance to the departments and agencies responsible for the design, development, test, installation, and operation of the system and to document design decisions reached to date. This system specification will become a coordinated DoD document, and will continue to be updated as more detailed and refined system engineering becomes available and as the impact on the design of the system of equipment development programs becomes apparent. The relationship between the terrestrial digital portions of the DCS described herein and the Defense Satellite Communications System (DSCS) is discussed in TR 12-76, DCS Digital Transmission System Performance.

1.1 MISSION

The mission of the Terrestrial Digital Transmission System shall be to provide bulk encrypted, high quality, high availability transmission of communications throughout the Defense Communications System. The system will be oriented to digital transmission, and be capable of transitioning from the analog systems currently in use to the digital system described in the DCA Long Range Plan.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this specification to the extent specified herein.

SPECIFICATIONS

CCC-74048	Specification for Multiplexer/Demultiplexer TD-1193( )/F
CCC-74047	Specification for Multiplexer/Demultiplexer TD-1192( )(CP)/F
CCC-74049	Specification for Radio Set AN/FRC-163( )
TT-B1-1101-0001	Performance Specification, Central Office Communications, AN/TTC-39(V)
TT-B1-6002-0069	Performance Specification for Tenley Trunk Encryption Device

STANDARDS

MIL-STD-130	Identification Marking of US Military Property
MIL-STD-188-100	Common Long Haul and Tactical Communications System Technical Standards
MIL-STD-189	Rack, Electrical Equipment, 19-inch and Associated Panels
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-463	Definitions and System of Units, Electromagnetic Interference Technology
MIL-STD-471	Maintainability Verification/Demonstration/ Evaluation
MIL-STD-781	Reliability Test: Exponential Distribution
MIL-STD-810	Environmental Test Methods
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities

PROPOSED

MIL-STD-188-114	Electrical Characteristics of Digital Interface Circuits

3. REQUIREMENTS

3.1 SYSTEM DEFINITION

3.1.1 GENERAL DESCRIPTION

The Terrestrial Digital Transmission System, herein after called "the system" shall consist of those equipments which, when combined with the necessary facilities, personnel, and support, furnish high quality multichannel digital communications via line-of-sight (LOS) and tropospheric scatter (tropo) radio paths between terrestrial installations. The communications services to be provided by the system shall include, but not be limited to, analog voice, secure digitized voice, digital data at standard rates, quasianalog signals, facsimile, imagery, and special digital services at rates up to approximately 12.9 Mb/s.

3.1.1.1 FUNCTIONS

The functions to be performed by the system shall include:

a. Analog/digital conversion of nominal 4 kHz analog signals
b. Digital multiplexing and supervisory signalling
c. Digital radio transmission and reception
d. Bulk encryption

e. Transmission system status monitoring, control and restoral

3.1.1.2 CHANNEL SERVICES

The system shall provide the following channel services to the DCS:

a. Analog 4 kHz channels - nominal 4 kHz voice bandwidth channels in accordance with 4.4.3.2 of MIL-STD-188-100 plus associated E&M supervisory signalling, for the transmission of clear voice, quasianalog data, facsimile and all other services intended for usage via nominal 4 kHz VF channels.

b. 50 kb/s asynchronous data - transmission of a serial digital bit stream at a rate of 50 kb/s plus or minus 12.5 b/s with timing not synchronized to the system timing.

c. 16000×2^N synchronous data - transmission of a serial digital bit stream at rates of 16 kb/s, 32 kb/s, 56 kb/s, 64 kb/s, 128 kb/s, 256 kb/s and 512 kb/s with timing synchronized to the system timing.

d. Wideband data - transmission of a serial digital bit stream at nominal rates of 1.544, 3.088 and 6.176 Mb/s with timing either synchronized or not synchronized to the system timing and at rates of approximately 9.5 and 12.6 Mb/s (to be determined during equipment design phase) with timing synchronized to that of the digital radio terminal.

e. Low speed data - transmission of a serial digital bit stream at rates of 75×2^N b/s from 75 to 9600 with timing synchronized to the system timing, at asynchronous rates of 45.5, 50 and 74.2 b/s and at isochronous rates of 37.5, 56.8, 61.1 and 75 b/s.

3.1.1.3 FUNCTIONAL ELEMENTS

The system shall be composed of the following functional elements (See Fig A-1):

a. Level 1 pulse code modulation (PCM) multiplexer
b. Level 2 time division multiplexer (TDM)
c. Level A 16000×2^N TDM submultiplexer
d. Level B low/medium speed TDM submultiplexer
e. Service channel multiplexer
f. Service channel terminal
g. Digital radio set
h. Clock and timing subsystem
i. Bulk encryption
j. Transmission status monitoring and control (TSMC)
k. Patch and test
l. Station and facilities support

The basic function of each functional element shall be as described below.

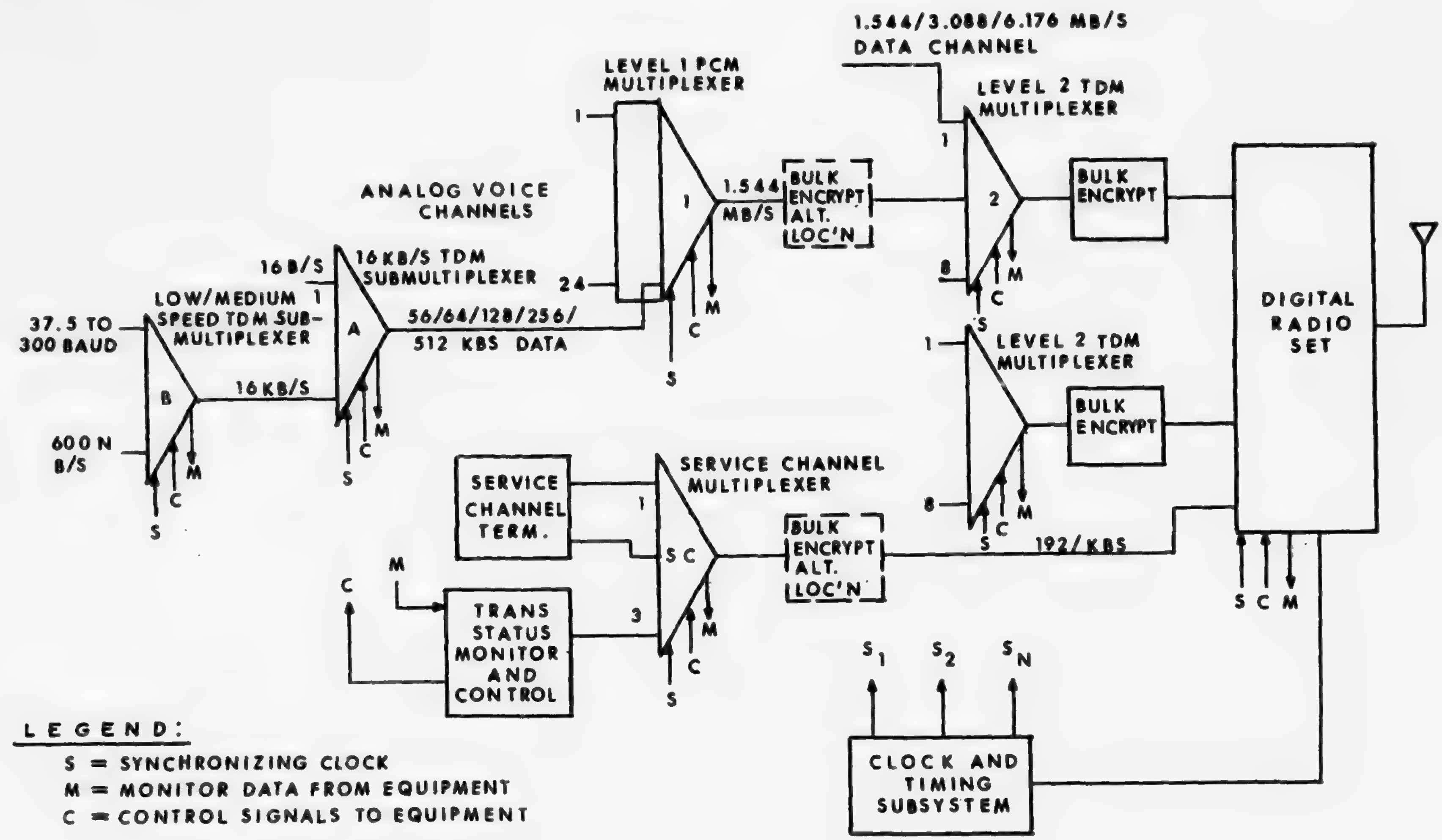


FIGURE A-1. DIGITAL-TRANSMISSION SYSTEM FUNCTIONAL BLOCK DIAGRAM

3.1.1.3.1 LEVEL 1 PCM MULTIPLEXER

The Level 1 PCM multiplexer shall process 24 voice channels into a combined digital bit stream using 64 kb/s PCM. The bit rate of the combined digital stream (digroup) shall be 1.544 Mb/s. The PCM analog-to-digital conversion, the multiplexing and the overhead format of this digroup shall be compatible with either the Western Electric D2 or D3 PCM multiplexers on an end-to-end basis. It shall be possible to replace up to 12 of the voice channels in each digroup with digital data channels of any of the following types:

a. 50 kb/s asynchronous - 50 kb/s clocked by source.
b. 56 or 64 kb/s synchronous - clocked by PCM multiplexer.
c. 128, 256 or 512 kb/s synchronous - clocked by PCM multiplexer.
d. 0-20 kb/s asynchronous - no associated clock (to be transmitted by transitional encoding or an equivalent technique).

Each channel of each of the above data sources except (c) shall displace one voice channel. Each 128, 256 or 512 kb/s data channel shall displace two, four or eight voice channels, respectively. Conversion of any voice channel to any of the above data channel capabilities shall require only replacement of channel related cards or modules. Each voice channel of the PCM multiplexer shall be equipped with an E and M supervisory signalling capability.

3.1.1.3.2 LEVEL 2 TIME DIVISION MULTIPLEXER

The Level 2 TDM multiplexer shall combine/decombine from two to eight nominal 1.544 Mb/s digital bit streams (digroups) into a single combined bit stream. The single digital bit stream at the combined side of the TDM shall be at rates which correspond to 2, 4, 6 or 8 digroups plus necessary overhead. The rates for 4, 6 and 8 digroups shall be 2, 3 and 4 times the rate for two digroups, respectively. For configurations in which 1, 3, 5, or 7 digroups are input to the TDM, the rate of the next higher even number of digroups shall be used. The TDM shall accept digroups whose timing is either synchronous or asynchronous with respect to the TDM timing. Asynchronous digroups shall have an input bit rate tolerance of plus or minus 200 b/s and shall be transmitted using pulse stuffing techniques. Synchronous digroups shall be transmitted without pulse stuffing. The TDM shall also accept a single 3.088 Mb/s plus or minus 400 b/s bit stream in place of two digroups or a 6.176 Mb/s plus or minus 600 b/s bit stream in place of four digroups. The 3.088 Mb/s and 6.176 Mb/s bit streams shall be capable of transmission in either the synchronous or asynchronous mode.

3.1.1.3.3 LEVEL A 16000x2^N TDM SUBMULTIPLEXER

The 16000x2^N digital submultiplexer shall combine three 16 kb/s

synchronous digital bit streams plus a suitable overhead bit stream into a single 56 kb/s digital bit stream or shall combine seven 16 kb/s or three 32 kb/s synchronous digital bit streams plus a suitable overhead bit stream into a single 128 kb/s digital bit stream. The overhead bit streams shall, in each case, be an 8000N b/s bit stream, synchronous with, the traffic bit streams and shall be formatted in accordance with the AN/TTC-39 switch overhead channel requirements as specified in TT-B1-1101-0031, Performance Specification, Central Office Communications, AN/TTC-39( )(V). The $16000x2^N$ submultiplexing function shall interface on its combined side with the 56 kb/s and the 128 kb/s data input/output ports of the 1st level PCM multiplexer. The 7 channel, 128 kb/s submultiplexer function may be implemented by circuitry internal to the AN/TTC-39 switch, by a channel reassignment unit similar to that used in the AN/GSQ-111 Communications Nodal Central Element, or by a separate $16000x2^N$ TDM submultiplexer.

3.1.1.3.4 LEVEL B LOW/MEDIUM SPEED TDM SUBMULTIPLEXER

The Level B low/medium speed TDM submultiplexer shall combine appropriate numbers of digital data channels at rates of 75 x 2 (N=0, 1, ...7) b/s and 37.5, 45.5, 50 50, 56.8, 61.1 and 74.2 b/s into combined bit streams at 16, 56 or 64 kb/s, suitable for interface with the 56 or 64 kb/s data channels of the 1st level PCM multiplexer or one channel of the $16000x2^N$ TDM submultiplexer. The low/medium speed TDM submultiplexing function shall be implemented in one or more equipments which provide a logical grouping of rates. The specific capabilities of these submultiplexers will be determined later.

3.1.1.3.5 SERVICE CHANNEL MULTIPLEXER

The service channel multiplexer shall derive channels for voice and telemetry service functions in support of the system. Two voice channels plus one telemetry channel shall be multiplexed together into a combined digital bit stream with a rate of 192 kb/s. The voice channels shall be derived using 64 kb/s PCM. The telemetry channel shall be implemented in the 3rd 64 kb/s channel.

3.1.1.3.6 SERVICE CHANNEL TERMINAL

The service channel terminal function shall provide all required VF termination, bridging and signalling capability necessary to interconnect individual service channels into multipoint networks suitable to support maintenance needs. This function may be satisfied by existing, in-place equipment where appropriate.

3.1.1.3.7 DIGITAL RADIO SET

The digital radio set function shall provide RF transmission and

reception for LOS and tropo microwave radio relay paths.

3.1.1.3.7.1 LOS DIGITAL RADIO SET

The LOS digital radio set functions for LOS links shall accept separate mission bit streams from one or two Level 2 TDM multiplexers plus a service channel bit stream from a service channel multiplexer and shall provide space diversity or frequency diversity transmission of these signals in the 4400-5000 MHz and the 7125-8400 MHz frequency bands. The LOS digital radio function shall provide transmission of the mission digroup cross-sections specified in Table A-I in the emission bandwidths as listed. Service channel requirements are not included in the specified digroup capacity but must also be implemented within the emission bandwidth. Where two emission bandwidths are listed, they represent the requirement for operation with two different spectral efficiencies (b/s/Hz).

TABLE A-I

EMISSION BANDWIDTH REQUIREMENTS FOR DIGROUP CAPACITIES OF LOS DIGITAL RADIO SET

DIGROUP CAPACITY	EQUIVALENT VF CHANNELS	EMISSION BANDWIDTH (MHz)
2	48	3.5
4	96	3.5, 7.0
6	144	7.0, 10.5
8	192	7.0, 14.0
12	288	10.5, 20
16	384	14, 20

(3.5 MHz bandwidth required in 4400-5000 MHz band only)
(10.5 and 20 MHz bandwidth required in 7125-8400 MHz band only)

Capacities of 2 and 6 digroups shall be provided by a single input mission bit stream. Capacities of 4 or 8 digroups shall be provided by either a single or two equal input mission bit streams. Capacities of 12 or 16 digroups shall be provided by two equal input mission bit streams. When two mission bit streams are input to the radio terminal they shall be at equal bit rates.

The radio terminal function shall contain a time base capable of being synchronized to a station timing source. In the absence of a station timing source, the radio set function shall provide timing to synchronize all directly subordinate multiplexers. The LOS digital radio set function shall be satisfied with either a self-contained digital radio set or with a digital applique unit operating with an existing FM radio terminal.

3.1.1.3.7.2 TROPO DIGITAL RADIO SET

The tropo digital radio set function shall accept separate mission bit streams from a Level 1 PCM multiplexer or from one or two Level 2 TDM multiplexers plus a service channel bit stream from the service channel multiplexer and shall provide diversity (typically dual or quad) transmission of these signals in the 790-960 MHz, 1700-2690 MHz and 4.4-5.0 GHz frequency bands. The digital tropo terminal shall provide transmission of the mission digroup cross sections specified in Table A-II in the indicated emission bandwidth. Service channel requirements are not included in the specified digroup capacity but must also be implemented within the listed emission bandwidths. Where two emission bandwidths are listed, they represent the requirement for operation with two different spectral efficiencies (b/s/Hz).

TABLE A-II

EMISSION BANDWIDTH REQUIREMENTS FOR DIGROUP CAPACITIES OF TROPO DIGITAL RADIO SET

DIGROUP CAPACITY	EQUIVALENT VF CHANNELS	EMISSION BANDWIDTH (MHz)
1	24	3.5
2	48	3.5, 7
4	96	10.5, 14.0
6	144	10.5, 14.0
8	192	14.0

Capacities of 1 and 6 digroups shall be provided by a single input mission bit stream. Capacities of 2, 4 and 8 digroups shall be provided by either a single or two equal rate mission bit streams.

The tropo digital radio set function shall contain a time base capable of being synchronized to a station source. In the absence of a station timing source, the tropo digital radio set shall provide timing to synchronize all directly subordinate multiplexers. The tropo digital radio set function shall be implemented through the use of a digital tropo modem in conjunction with existing up-converter and down-converter equipment.

3.1.1.3.8 CLOCK AND TIMING SUBSYSTEM

The clock and timing subsystem shall generate all necessary synchronized bit rate timing signals for distribution to all encryption units, digital multiplexers, submultiplexers and digital radio sets within a station. The clock and timing subsystem shall contain: (1) a station master clock capable of being coordinated with other clocks in the network, (2) a clock distribution unit which generates and disseminates required

timing signals within the station, and (3) link interfaces between the station clock and transmission links which provide those functions necessary for the operation of the selected network synchronization techniques. The link interface shall also contain any required buffering to normalize propagation delay variation on transmission links. In the asynchronous mode of network operation, outgoing timing in each station shall be based on the master oscillator in each radio set if no clock and timing subsystem is provided. If a clock and timing subsystem is provided it shall coordinate all outgoing timing within the station. In the synchronous mode of operation, (1) all stations shall be provided with a clock and timing subsystem, (2) all station clock and timing subsystems within the network shall be coordinated and (3) the clock and timing subsystem shall clock all outgoing and incoming signals within the station.

3.1.1.3.9 BULK ENCRYPTION

The bulk encryption function shall accept digital NRZ bit streams plus associated timing at digroup or higher data rates within the system and provide encryption of that data stream. The bulk encryption function shall be capable of operating at either the 1.544 Mb/s digroup bit rate or at any of the Level 2 TDM multiplexer output rates described in 3.1.1.3.2. The bulk encryption function shall be capable of being externally commanded to synchronize/resynchronize and shall be equipped with an externally commanded clear text bypass capability.

3.1.1.3.10 TRANSMISSION STATUS MONITORING AND CHANGE (TSMC)

The TSMC function shall provide all necessary test, monitoring, signal processing and control functions necessary to determine transmission system status and to effect transmission system control. It shall receive all status monitoring indications from equipment at the site, including equipment fault indications, operational status, power indications and station indications. All necessary on-site processing of these signals necessary to accomplish local control actions shall be performed. All necessary multiplexing of these signals for application to the telemetry channel and all necessary control of the telemetry channel shall be accomplished. This function shall provide the necessary coordinated control of multiplexer resynchronization, standby equipment switching and crypto equipment bypass switching. Additionally, control channels shall be provided in conjunction with the telemetry service channel to effect remote operation of standby switching, resynchronization, and crypto switching.

3.1.1.3.11 PATCH AND TEST - to be provided in a later issue

3.1.1.3.12 STATION AND FACILITIES SUPPORT

The station and facilities support function shall provide physical housing, environmental conditioning, primary power, grounding and interconnecting cabling capabilities for the other elements of the system.

3.1.1.4 SYNCHRONIZATION MODES

The system shall be capable of operating in either a synchronous or an asynchronous mode. Asynchronous mode will be utilized as a transitional mode of the system since it is not anticipated that the intersite clock coordination capabilities will be available for initial system operation. During this period most channels will be analog, and therefore have no synchronous requirement. As station synchronization capabilities are implemented, the interconnected sites of the system will be converted to synchronous mode. In the asynchronous mode, timing sources in the various interconnected sites of the system will not be synchronized. Asynchronous, pulse stuffing techniques will be necessary to multiplex digital signals originating from separate non-synchronized sites. Asynchronous signals will be accommodated at 50 kb/s and at 1.544 Mb/s, 3.088 Mb/s and 6.176 Mb/s. In the synchronous mode, all timing sources of the system will be in synchronism with each other. Use of this mode is activated by accomplishing synchronization between station clocks at all stations in the system. Use of synchronous mode allows the direct interconnection of digital signals originating at various points througuout the network. Synchronous multiplexing shall be used to multiplex all digital signals which are contained within the synchronized part of the net. Digital signals which are originated at stations external to the synchronous network shall be accommodated at 50 kb/s, 1.544 Mb/s, 3.088 Mb/s or 6.176 Mb/s using pulse stuffing asynchronous channels.

3.1.1.5 EXISTING SYSTEM COMPATIBILITY

3.1.1.5.1 LOS DIGITAL RF LINK EQUIPMENTS

LOS digital RF link equipments shall, to the maximum extent practical, be capable of meeting all requirements specified herein on existing DCS radio paths using existing antennas and waveguide runs.

3.1.1.5.2 DIGITAL APPLIQUE UNIT COMPATIBILITY

The digital applique unit (see 3.1.1.3.7.1) shall be capable of meeting all applicable requirements of this specification when operated in conjunction with any of the following existing FM radio terminals:

a. AN/FRC-159 through 162
b. MR-300
c. LC-4
d. LC-8

3.1.1.5.3 TROPO DIGITAL MODEM

The requirements for a tropo digital radio function specified herein shall be met through the use of a tropo digital modem interfaced at 70 MHz with the following existing DCS up-converter/down-converter equipments:

a. AN/FRC-39A
b. AN/FRC-96
c. AN/FRC-97
d. AN/MRC-113
e. AN/MRC-85
f. AN/TRC-170
g. AN/FRC-132, 132A
h. LRC-3

3.1.1.5.4 LEVEL 2 TDM MULTIPLEXER COMPATIBILITY

The Level 2 TDM multiplexer shall be capable of interfacing and operating with the CY-104, the Western Electric D2/D3 channel bank and the AN/GSC-24(V) at the digroup rate (1.544 Mb/s).

3.1.2 THREAT

The threats to the transmission subsystem include sabotage, jamming and nuclear detonations. Protection of the system against sabotage shall be accomplished by military means and by normal facility/site construction methods and/or location. The extent of the jamming threat in Europe is detailed in Draft final report of the European Command, Control and Communications Study Group, 25 April 1975, Appendix C - "Threat to Europe C3." Protection of the system against jamming shall be as discussed in section 3.2.5 of this specification. Protection of the system against the nuclear threat is described in section 3.2.7 of the specification.

3.1.3 SYSTEM DIAGRAMS

To enable the system to provide the many capabilities anticipated in the DCS application, a wide variety of configurations must be provided. These configurations are diagrammed and described in the following paragraphs. The equipment elements making up these configurations are described in 3.1.1.3 and 3.6.

3.1.3.1 SYSTEM CONFIGURATIONS

The system configurations include a repeater configuration, a

branching repeater configuration, and a terminal configuration with through-grouped multiplexers as well as drop and insert.

3.1.3.1.1 REPEATER CONFIGURATION

The repeater configuration illustrated in Figure A-2 shall receive, regenerate and retransmit RF signals in each direction. A repeater shall be capable of unattended operation and no demultiplexer/multiplexer is required for any component part of the mission bit stream. Service channel access shall be provided to allow a communications capability for maintenance personnel, and to allow telemetry of alarm and control functions of the other equipments. The received RF signal shall be demodulated to baseband and separated into separate mission bit streams and the service channel bit stream. The mission bit streams and the associated recovered timing shall be passed directly to the transmitter in the outgoing direction where they shall be recombined with the service channel, remodulated, and transmitted to the next station. The service channel multiplexer unit provides three channels, two of which provide voice orderwires. The third channel provides a digital data orderwire connection to the TSMC unit.

3.1.3.1.2 BRANCHING REPEATER CONFIGURATION

A branching repeater, Figure A-3, shall interconnect three or more transmission paths and shall provide for any combination of interconnection of digroups among the various paths. Thus the mission bit streams associated with each path will generally be demodulated to the digroup level but no channels will be demodulated to the VF level. In the asynchronous mode of network operation it shall be possible to through-route a single mission bit stream without demodulation to the digroup level, as shown in Figure A-3. In the synchronous mode of network operation, additional mission bit streams may be through-routed. The service channel and telemetry functions at the branching repeater are the same as those described for the repeater configuration (3.1.3.1.1). A branching repeater shall, in the synchronous mode, contain a Clock and Timing Subsystem.

3.1.3.1.3 TERMINAL CONFIGURATION

A terminal configuration shall provide channel breakouts to the voice level. Other functions shall include through-routing of mission bit streams, and through-routing of digroups. The following description describes a terminal configuration which is connected to two communication paths. It contains all terminal configuration functions. A terminal configuration with three or more paths shall contain additional repetition of the functions described below. A terminal configuration connected to a single path shall contain no through-routing. The terminal configuration connected to two paths illustrated in Figure A-4

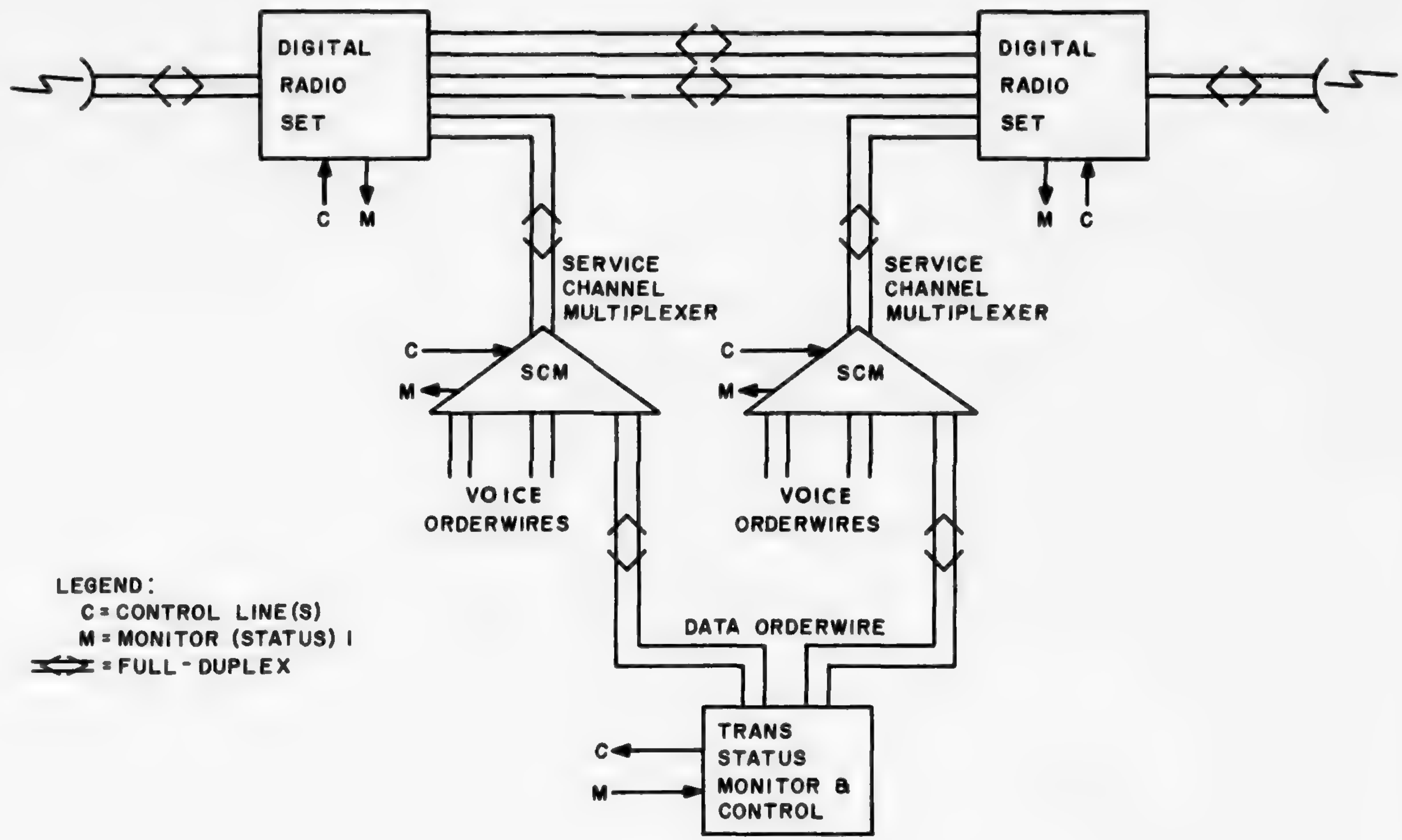


FIGURE A-2. REPEATER CONFIGURATION

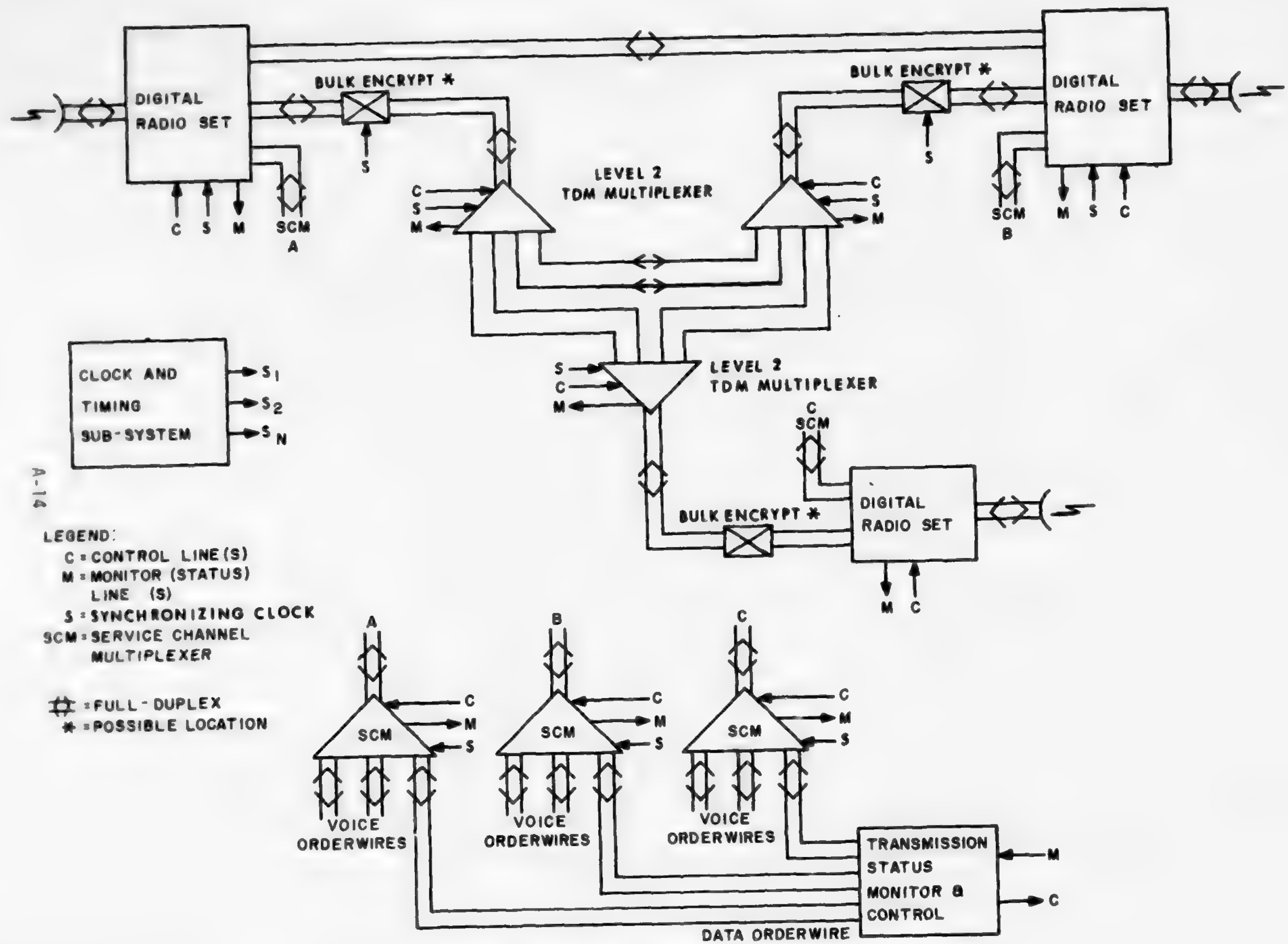


FIGURE A-3. BRANCHING REPEATER CONFIGURATION

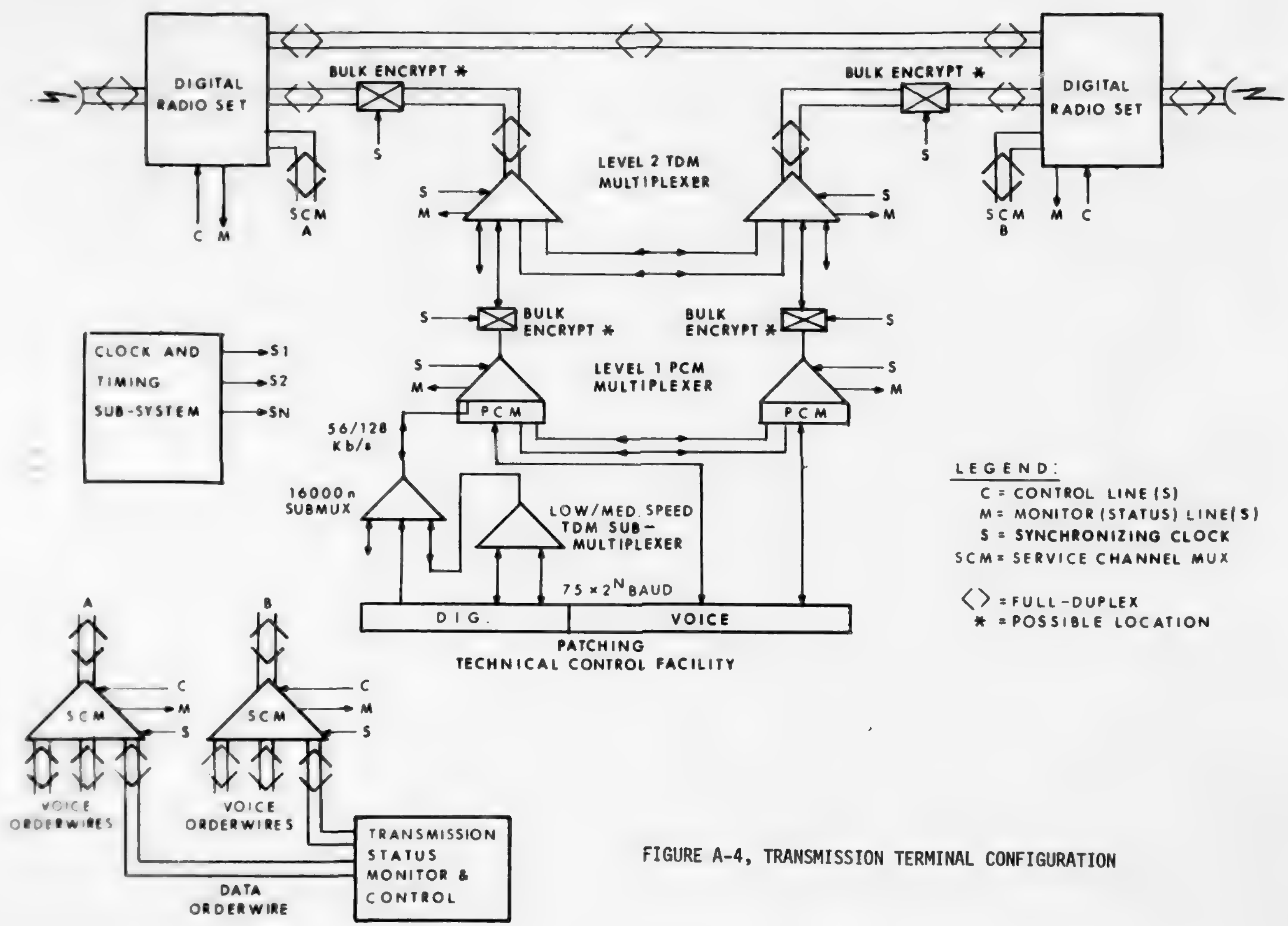


FIGURE A-4, TRANSMISSION TERMINAL CONFIGURATION

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DCS DIGITAL TRANSMISSION SYSTEM PERFORMANCE.(U)
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UNCLASSIFIED TR-12-76 NL

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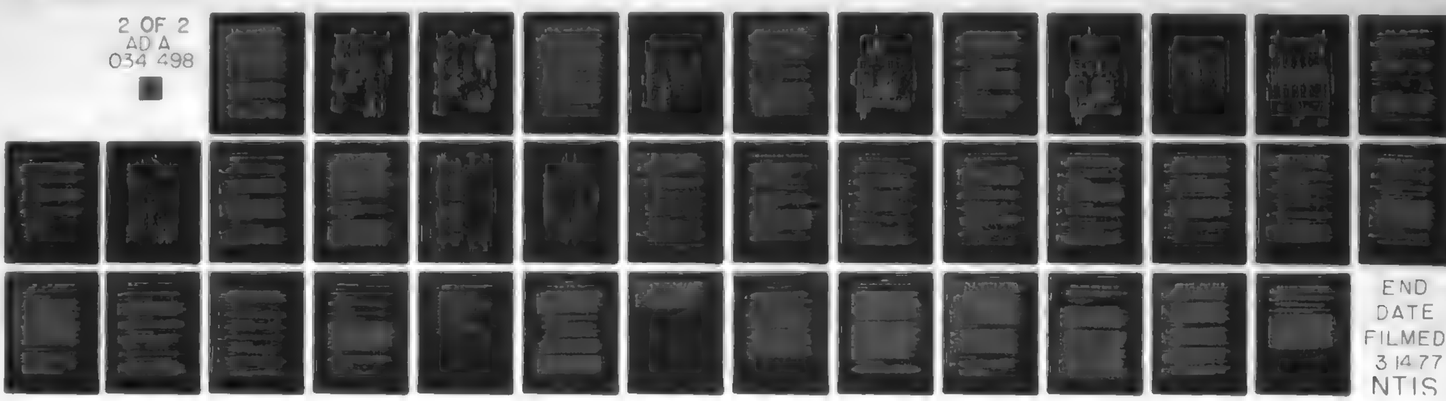

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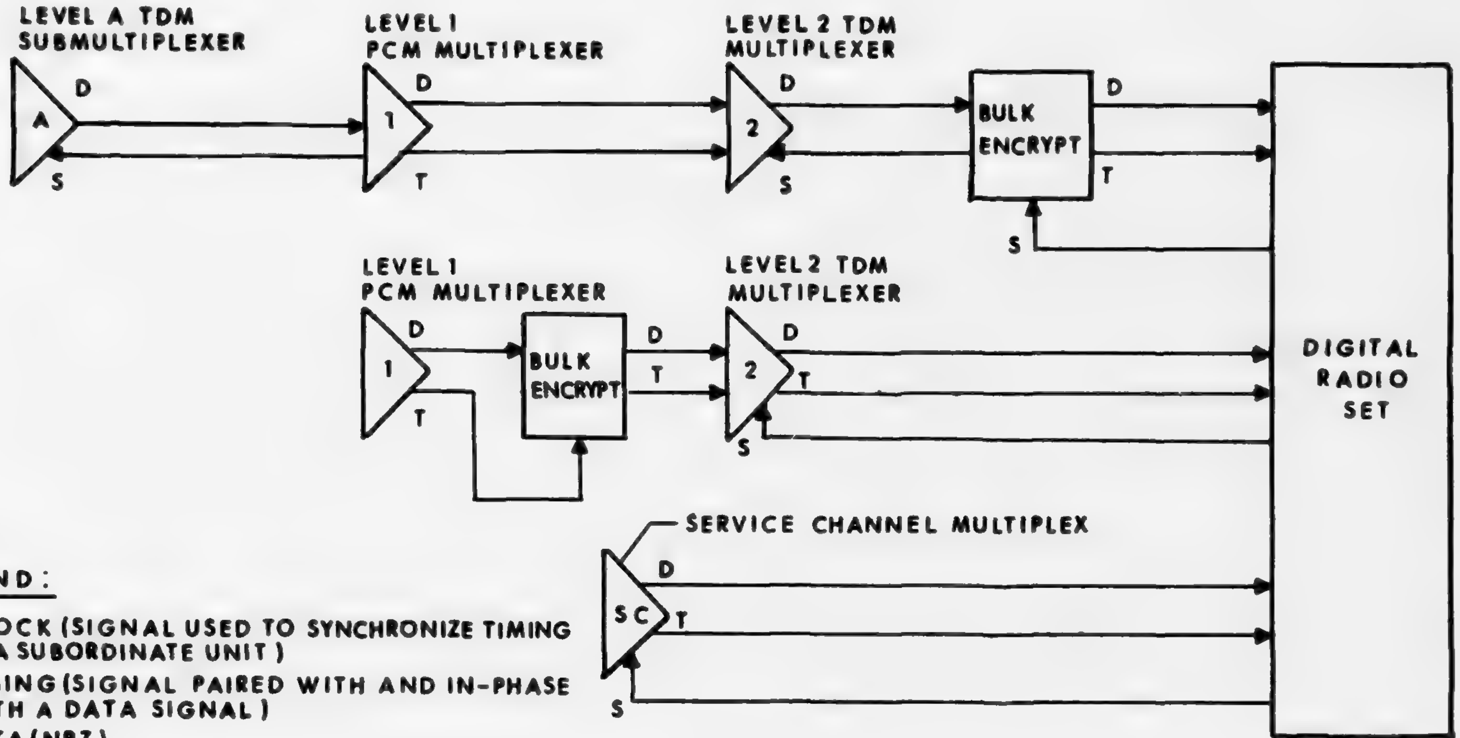
provides both through-routing functions and a capability to provide a number of mission analog and digital breakouts at the voice level for users located in the vicinity of the terminal. One mission bit stream is through-routed from the receiver directly to the outgoing transmitter. The second mission bit stream, which contains channels to be dropped and vacant channel assignments which can be occupied by inserted channels, is demultiplexed by a Level 2 TDM multiplexer. Digroups demultiplexed by one Level 2 TDM multiplexer are shown being through-routed to the outgoing Level 2 TDM multiplexer. The digroups containing the voice channels of local interest are shown being demultiplexed by a Level 1 PCM multiplexer. Demultiplexed analog and digital voice channels are brought to corresponding digital and analog patch bays which are part of the TCF. Terminating channels are connected to terminal equipment and some channels are through-routed to the outgoing Level 1 PCM multiplexer. In synchronous mode any type of digital channels may be terminated or through-routed. In asynchronous mode, only the 50 kb/s, 1.544 Mb/s, 3.088 Mb/s and 6.176 Mb/s asynchronous channels may be through-routed. Digital channels may be further subdivided by TDM submultiplexers. The Level A TDM submultiplexer is configured either for three input channels of 16 kb/s each and a 56 kb/s output or for seven input channels of 16 kb/s each and a 128 kb/s output. The Level B low speed TDM submultiplexer will provide various low bit rate channels derived from a 16 kb/s digital channel of the Level A TDM submultiplexer. The service channel, TSMC, and Clock/Timing functions of the terminal configuration are essentially the same as those described in 3.1.3.1.2 for the Branching Repeater configuration.

3.1.3.1.4 CLOCK DISTRIBUTION

Two different configurations, one asynchronous and one synchronous, shall be provided for the distribution of clock at branching repeaters and terminals. The routing of timing shall be in accordance with MIL-STD-188-100, 4.3.1.6.3.1, Case Two, which requires timing to accompany data from source to sink. Clock is defined herein as a reference signal which determines the rate of digital transmission. Timing is defined as a signal that is companion to each data stream which is used by the data sink to sample the data stream.

3.1.3.1.4.1 ASYNCHRONOUS NETWORK CONFIGURATION

In the asynchronous mode the system shall provide either of two timing configurations. These are shown in Figures A-5 and A-6. Figure A-5 illustrates a terminal configuration without a clock and timing subsystem where transmit clock is generated by the timing source in the digital radio set transmitter or is derived from the timing of a through-routed mission bit stream. Figure A-6 illustrates the terminal configuration for transmit timing when a clock and timing subsystem is present. Receive timing, in



LEGEND:

S = CLOCK (SIGNAL USED TO SYNCHRONIZE TIMING IN A SUBORDINATE UNIT)

T = TIMING (SIGNAL PAIRED WITH AND IN-PHASE WITH A DATA SIGNAL)

D = DATA (NRZ)

NOTE:

DIGITAL RADIO SET AND LEVEL 1 PCM MUX USE OWN INTERNAL TIME BASE.

FIGURE A-5. TRANSMIT TERMINAL TIMING AND CLOCK CONFIGURATION
ASYNCHRONOUS MODE
NO CLOCK AND TIMING SUBSYSTEM

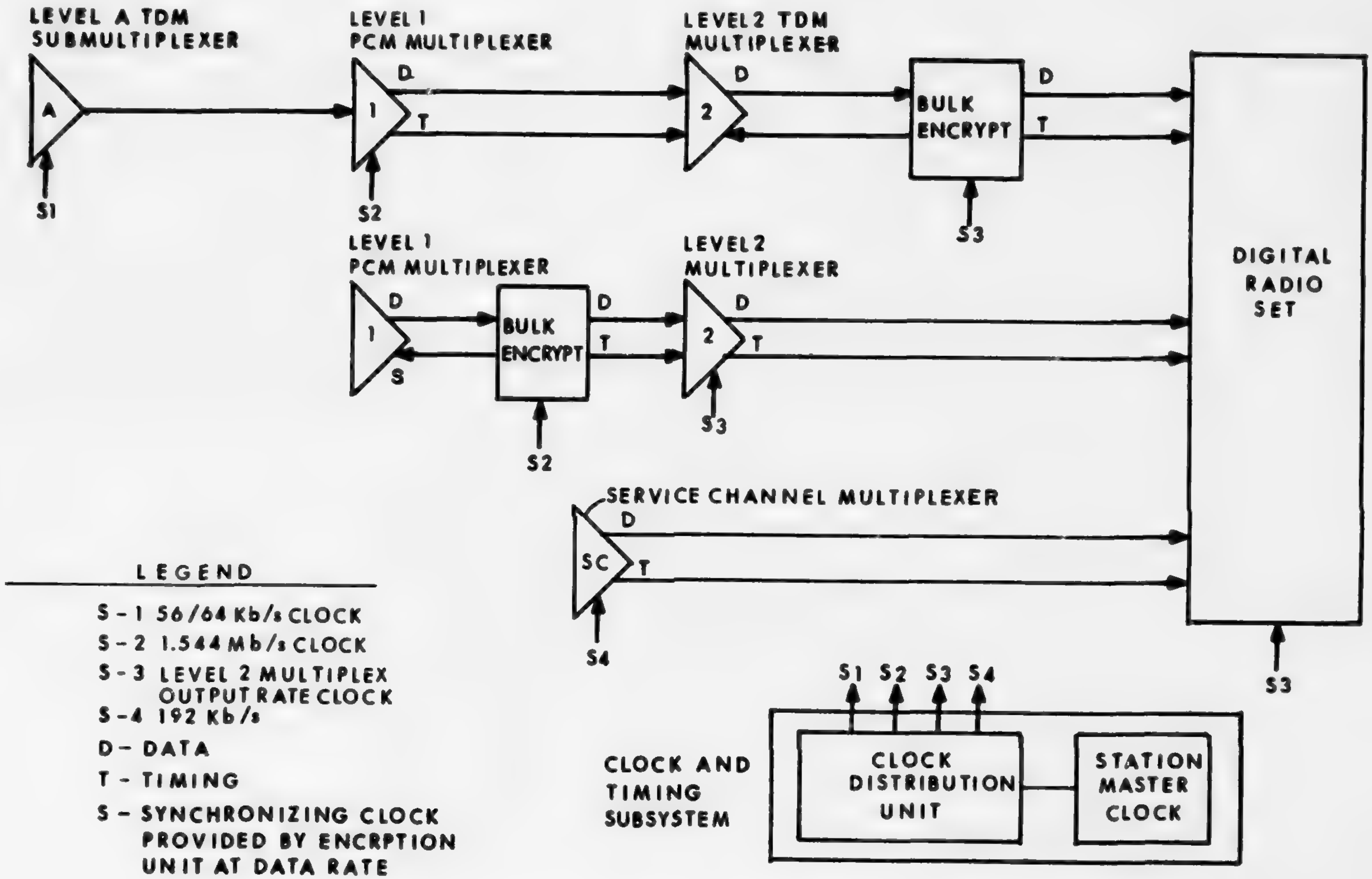


FIGURE A-6. TRANSMIT TERMINAL TIMING AND CLOCK CONFIGURATION, ASYNCHRONOUS MODE, WITH CLOCK AND TIMING SUBSYSTEM

all cases is derived in the digital radio set receiver from the incoming RF signal and is routed with the data from the receiver to the encryption unit to the Level 2 TDM multiplexer to the Level 1 PCM multiplexer. The receive terminal configuration illustrating the routing of receive timing is shown in Figure A-7.

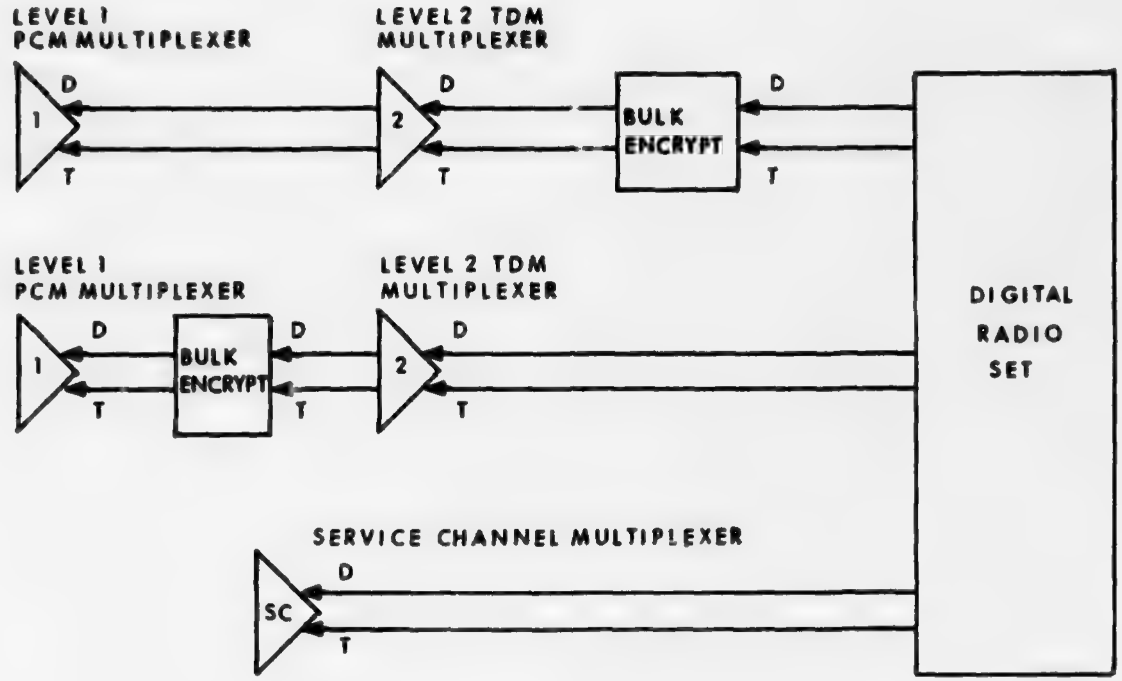
When no clock and timing subsystem is present, the timing derived from the digital radio set transmitter internal timing source shall serve as the clock source for all subordinate interfacing equipment. The transmitter internal timing source shall operate independently unless one of its mission bit streams is through-routed direct from a digital radio set receiver in the station. In this case, the transmitter internal timing source shall be slaved to the timing signal derived from the through-routed mission bit stream and shall provide a clock signal to each interfacing bulk encryption unit, Level 2 TDM multiplexer or service channel multiplexer. Each interfacing encryption unit shall accept clock from its directly interfacing transmitter. The encryption unit shall output that clock to its directly interfacing Level 2 TDM multiplexer which shall output data without a companion timing line based on that clock. The encryption unit shall have a strappable option to align the phase of the incoming data from the Level 2 TDM multiplexer to its clock. The transmitter shall contain the required buffering to accept two mission bit streams and one service channel bit stream with a common clock rate but with random phase and to align these phases as necessary for transmission.

The internal timing source of the Level 1 PCM multiplexer shall provide a clock to all subordinate digital equipments and users. Since the Level 1 PCM multiplexer clocks are not synchronized, the Level 2 TDM multiplexer asynchronous option shall be used. The digroup inputs of the Level 2 TDM multiplexer shall be aligned by pulse stuffing.

In the asynchronous mode the clock and timing subsystem shall be the local timing reference for all digital equipment in the facility that is not required to be synchronous with a distant source. The clock and timing subsystem is optional in the asynchronous mode but mandatory in the synchronous mode. The clock distribution unit of the clock and timing subsystem shall generate and buffer amplify all necessary clock signals for distribution to equipment throughout the facility. When a clock and timing subsystem is present in an asynchronous mode as shown in Figure A-6, all units except those directly subordinate to encryption units shall be provided clock by, and synchronized to, the clock and timing subsystem.

3.1.3.1.4.2 SYNCHRONOUS NETWORK CONFIGURATION

In the synchronous mode the terminal configuration is the same as that shown in Figure A-6 except that the clock and timing subsystem is synchronized to a network standard. A buffering function shall absorb propagation delay variations originating in



LEGEND

D - DATA
T - TIMING

FIGURE A-7. RECEIVE TERMINAL TIMING CONFIGURATION, ASYNCHRONOUS MODE

the media and equipment to maintain a constant rate into the facility in the receive direction. The Level 1 PCM multiplexers shall be clocked from the clock and timing subsystem unless an encryption unit is used at the digroup level, in which case the Level 1 PCM multiplexer is clocked by the encryption unit. Since the clock and timing subsystems in all stations are in synchronization, all Level 1 PCM multiplexers will be synchronous which will allow the Level 2 TDM multiplexers to operate in the synchronous option. All digital users serviced by the facility will be synchronized to the clock and timing subsystem of that facility.

A clock synchronization capability within the clock and timing subsystem shall be required for synchronous mode operation. This capability controls the variation of phase and/or frequency of the station clock and timing subsystem to within a specified tolerance of the rest of the network or of a specified reference. It will assure constant or quasi-constant digital rates at all stations, and thereby enable synchronous switching and multiplexing of digital signals originating anywhere throughout the network.

3.1.3.2 DIGITAL RADIO SET DIVERSITY CONFIGURATIONS

3.1.3.2.1 LOS DIGITAL RADIO SET

The line-of-sight radio set shall be provided in either a dual frequency diversity or a dual space diversity configuration. If additional diversity is required to meet availability requirements on specific links, the requirements for such provisions shall be determined on an individual case basis.

3.1.3.2.1.1 FREQUENCY DIVERSITY

The frequency diversity configuration illustrated in Figure A-8 shall consist of two radio sets with the transmitters tuned to different frequencies, and each normally radiating at all times. It shall also consist of diplexer filters and a combiner. The receivers shall be receiving at all times on a different pair of frequencies. The transmitters will be driven in parallel with the same digital signal. The receivers shall each demodulate the received signals independently. A receiver diversity combiner shall be provided in the radio terminal to combine the diversity signals. The combiner shall provide the following performance:

a. The switching or combining action of the combiner shall create no erroneous bits in the output stream.

b. The switching or combining action of the combiner shall not cause loss of BCI.

c. If a nonswitching combiner is used, a minimum of equal gain combining action shall be provided.

d. A switching function shall allow either receiver output to be manually or remotely switched off-line without introducing errors or loss of BCI.

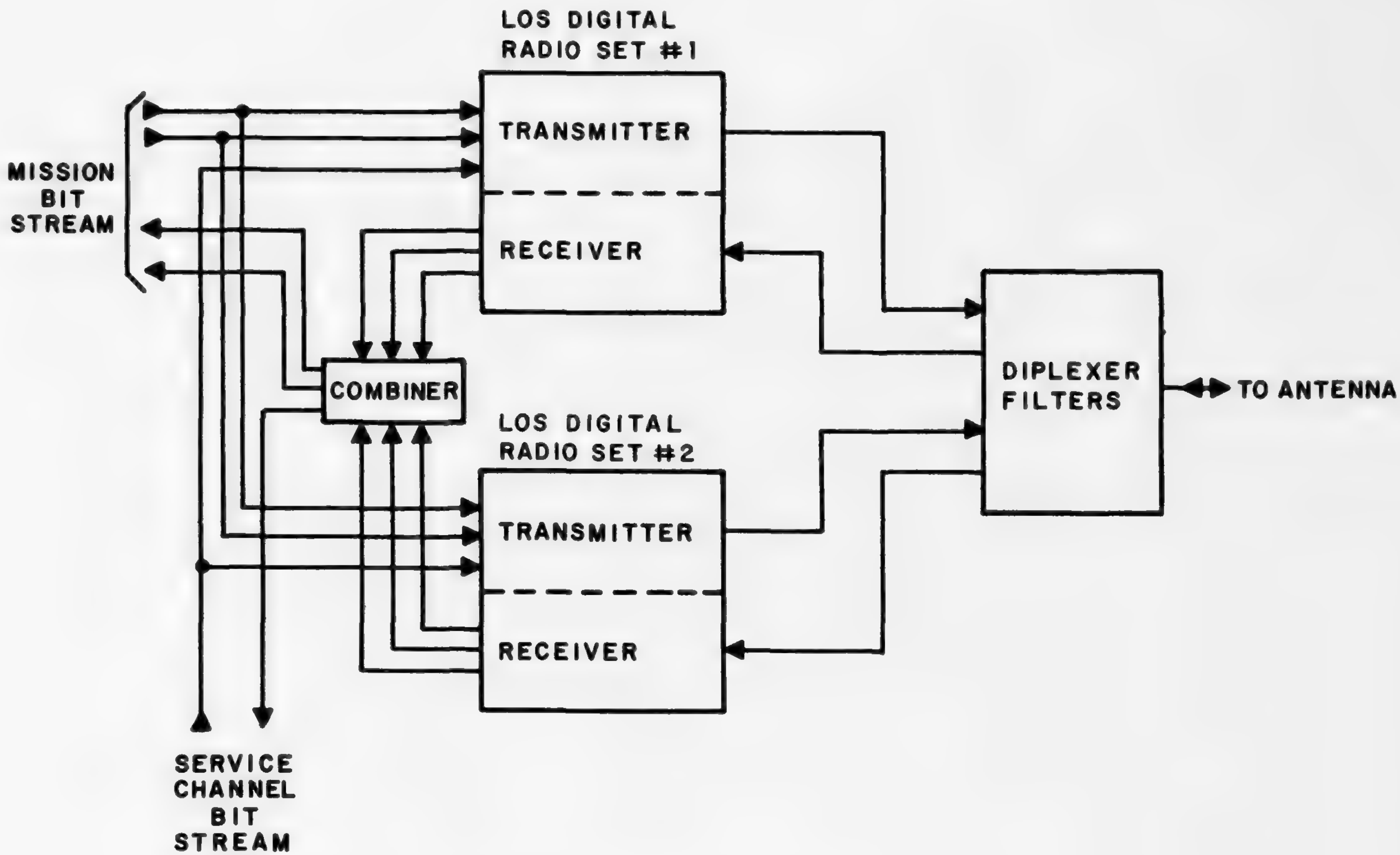


FIGURE A-8. FREQUENCY DIVERSITY CONFIGURATION OF LOS DIGITAL RADIO SET

3.1.3.2.1.2 SPACE DIVERSITY

The space diversity configuration illustrated in Figure A-9 shall consist of two LOS digital radio sets with the transmitters tuned to one frequency and the receivers tuned to a different frequency. One transmitter shall be connected to the antenna, while both receivers (operating from separate antennas) will be receiving and combining the incoming digital signals. Performance of the combiner shall be equivalent to that described for the frequency diversity terminal in 3.1.3.2.1.1 a. through d. when the input signals to the two receiving antennas vary in relative phase by any amount up to but not exceeding 20 nanoseconds and in BER by any ratio. Internally and externally (local and remote) controlled on-line/standby switching shall be provided for the transmitters and receivers.

3.1.3.2.2 TROPO DIGITAL RADIO SET

The tropo digital radio set shall operate in one of the following diversity configurations to meet particular requirements: frequency, frequency/space, space/polarization or other combinations. These configurations are described below.

3.1.3.2.2.1 FREQUENCY/SPACE DIVERSITY

The frequency/space diversity configuration illustrated in Figure A-10b and in more detail in Figure A-11 shall consist of two tropo digital radio transmitters and four tropo digital radio receivers. The transmitters are driven by identical signals from the tropo digital modem but transmit separate frequencies over separate antennas. Each pair of receivers is connected to a separate antenna, and each receiver of a pair is tuned to one of the two frequencies being received. The tropo digital modem shall (3.1.1.5.2) provide the function of diversity combining as well as demodulation.

3.1.3.2.2.2 FREQUENCY DIVERSITY

The frequency diversity configuration illustrated in Figure A-10a shall consist of two radio sets with the transmitters tuned to different frequencies, both radiating at all times, and driven in parallel by the same digital signal from the tropo digital modem. The receivers shall be receiving on this pair of frequencies at all times. As mentioned above, the tropo digital modem will provide the diversity combining function and demodulation.

3.1.3.2.2.3 SPACE/POLARIZATION DIVERSITY

Where dual frequency allocations are unavailable, space/polarization diversity shall be used. The space/polarization configuration shall consist of one tropo

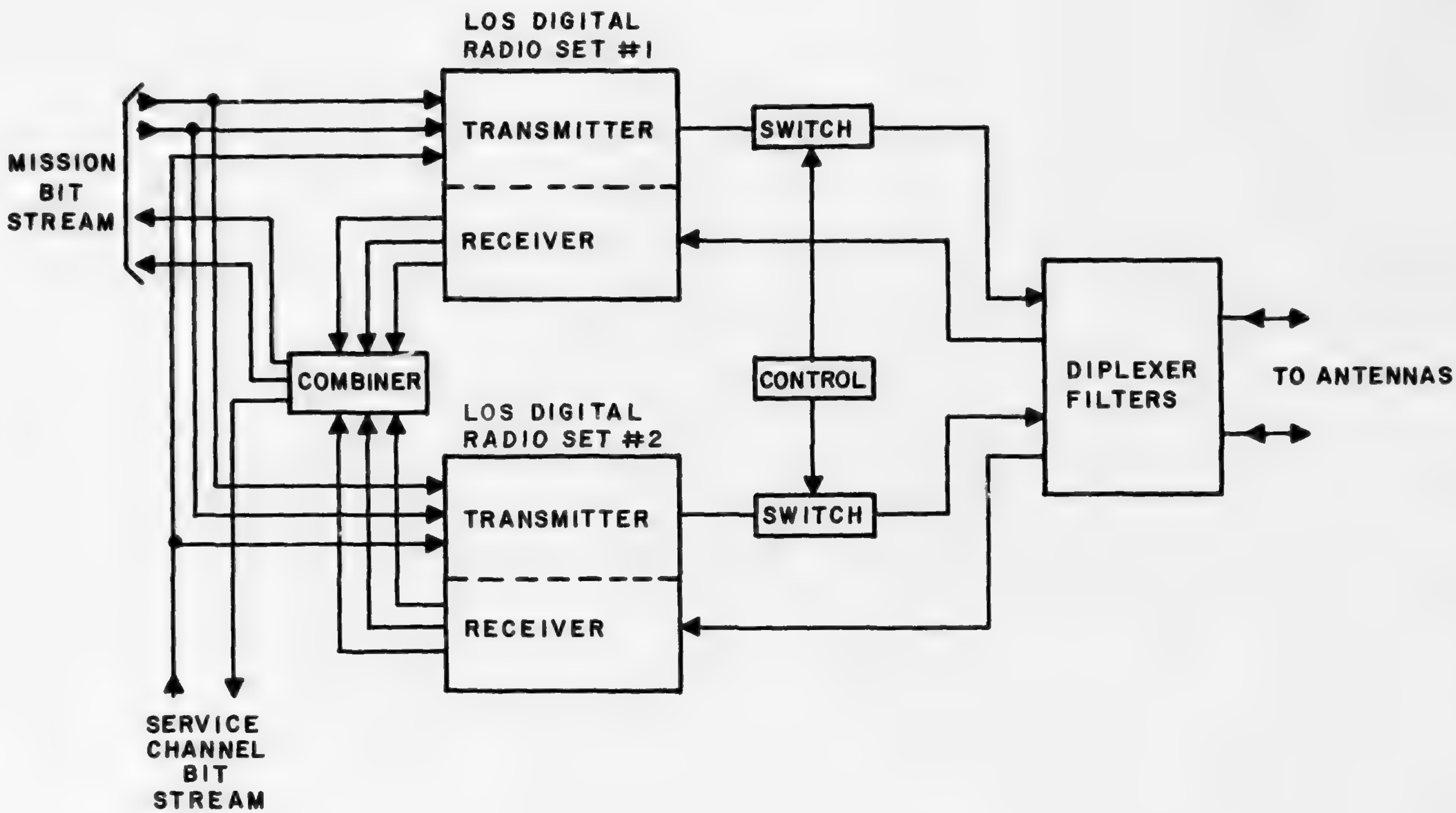


FIGURE A-9. SPACE DIVERSITY CONFIGURATION OF LOS DIGITAL RADIO SET

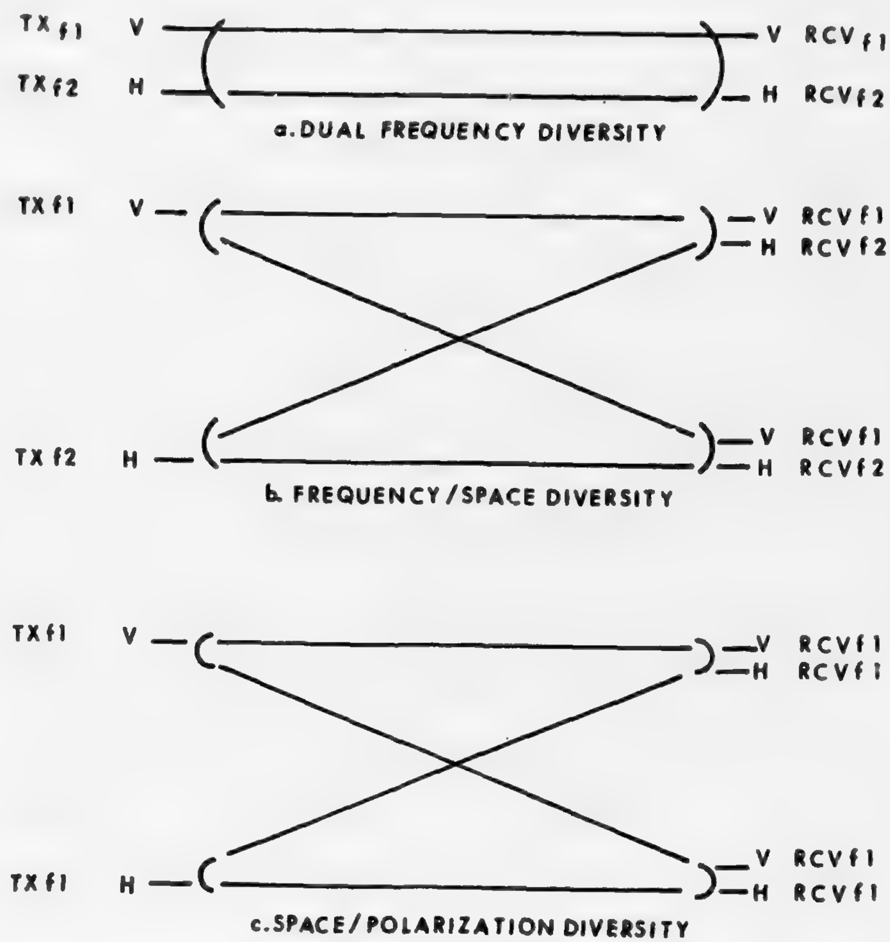


FIGURE A-10. TROPO DIGITAL RADIO DIVERSITY CONFIGURATIONS

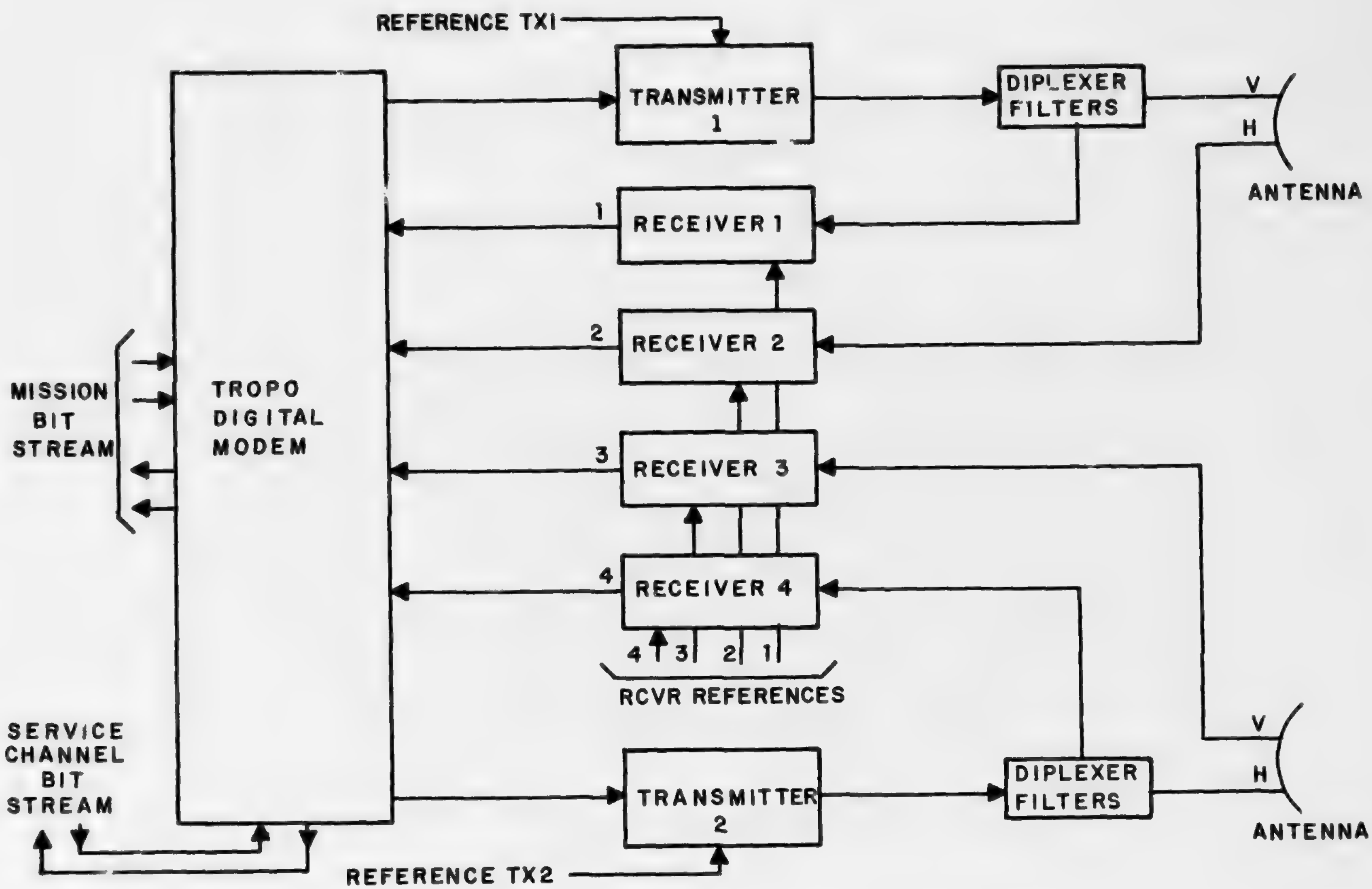


FIGURE A-11. DETAILED FREQUENCY/SPACE DIVERSITY CONFIGURATION OF TROPO DIGITAL RADIO

digital radio transmitter and four tropo digital radio receivers as shown in Figure A-10c. Diversity combiner functions shall be provided by a tropo digital modem in the same manner as for the frequency/space configuration above.

3.1.3.2.2.4 OTHER DIVERSITY CONFIGURATIONS

For more difficult links, additional fading protection such as angle diversity may be required for satisfactory performance. These configurations are non-standard and shall be approved by DCA and implemented on an as-required basis.

3.1.4 INTERFACE DEFINITION

3.1.4.1 CHANNEL INTERFACES

3.1.4.1.1 VF INTERFACE

The Level 1 PCM multiplexer channel VF input and output impedances shall each be 600 ohms +/-10 percent, balanced to ground. The VF input shall be either a 0 or -16 Transmission Level Point (TLP), selectable by a strapping option. The test-tone level at the VF output shall be either 0 dBm or +7 dBm, selectable by strapping option.

3.1.4.1.2 E&M SIGNALING

The PCM channel input and output interface conditions for E&M signaling shall be as follows:

	E LEAD	M LEAD
ON-HOOK	open	ground
OFF-HOOK	ground	battery (-48 volts +/- 5 volts)

3.1.4.1.3 DIGITAL INTERFACE

The digital interface for data and timing signals shall be a balanced voltage digital interface circuit that shall conform to paragraph 5.1 of Proposed Draft MIL-STD-188-114, 14 January 1976, titled: Electrical Characteristics of Digital Interface Circuits, superseding subparagraph 4.3.1.3 of MIL-STD-188-100, 15 November 1972. The circuit consists of three parts: the generator, the balanced interconnecting cable, and the load. The general characteristics of each part are given below; in the event of conflict, the requirements of MIL-STD-188-114 shall supersede.

3.1.4.1.3.1 GENERATOR

In general, the generator will be a low impedance (100 ohms or less) balanced voltage source that will produce a differential

voltage applied to the interconnecting cable in the range of 2 volts to 6 volts.

3.1.4.1.3.2 LOAD

In general, the load is a differential receiver having a high input impedance (greater than or equal to 4 kohms), a small input threshold transition region between -0.2 volts and +0.2 volts, and allowance for an internal bias voltage not to exceed 3 volts in magnitude.

3.1.4.1.3.3 INTERCONNECTING CABLE

In general, the cable will be a transmission line with a nominal characteristic impedance on the order of 100 ohms to frequencies greater than 100 KHz and a DC series loop resistance not exceeding 240 ohms.

3.1.4.2 CLOCK INTERFACE

The clock waveform will be a 50 percent duty cycle polar square wave with rise and fall times as shown in Figure A-12. The data and clock pulse output rise and fall time T_v and T_f shall be greater than 5 percent but less than 15 percent of the nominal data pulse width, I_d, at the highest applicable data rate at the interface when measured between the 10 percent and 90 percent points.

3.1.4.2.1 CLOCK RATES

In general, the clock rate shall be at the data bit rate of the equipment being provided with clock. Submultiplexers shall be provided with clock (if required) at the 64 kHz rate. Clock shall be provided (if required) to the Level 1 PCM multiplexer at 1.544 MHz.

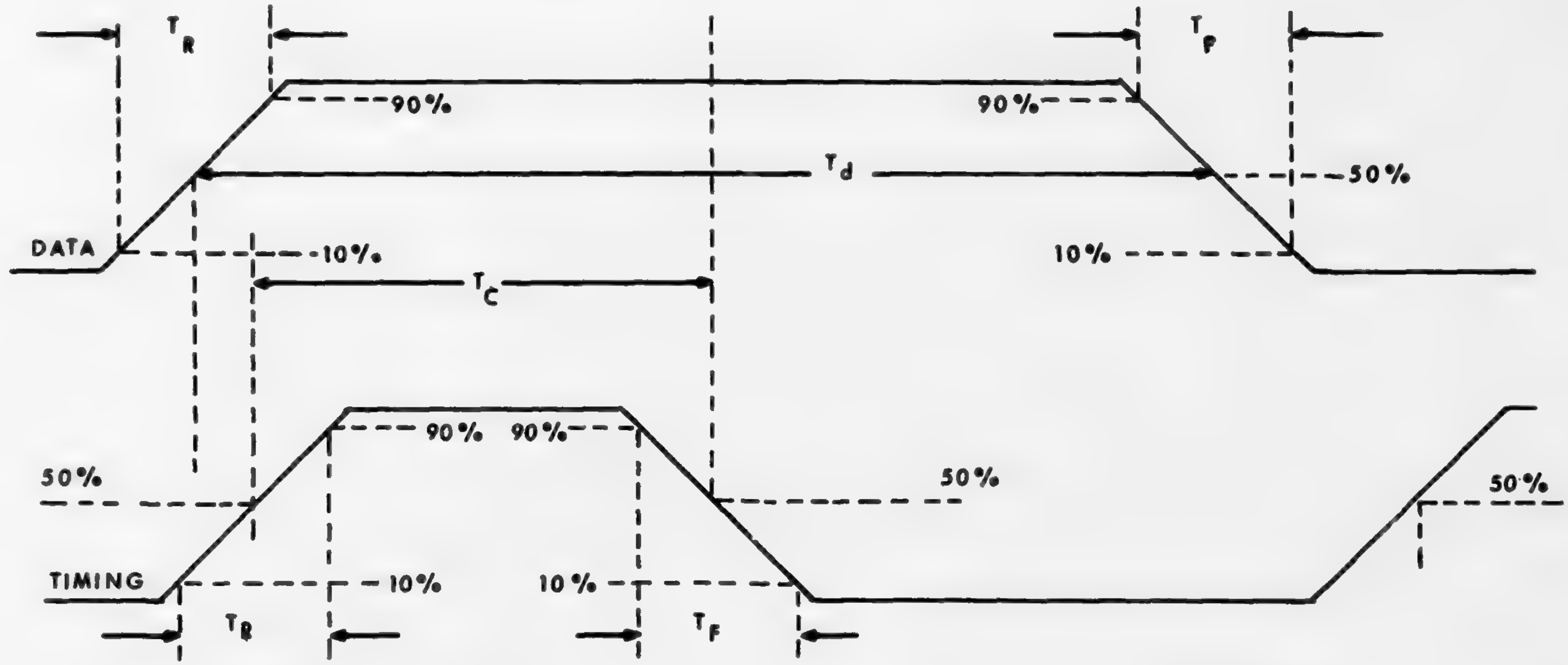
3.1.4.4 SYSTEM CONTROL AND ALARM

Interface signals shall be one of or a combination of three different types:

a. steady-state
b. pulse events, or
c. continuous DC varying levels.

3.1.4.4.1 STEADY-STATE SIGNAL

This is a signal actuated by a contact closure and is either on or off.



T_D = NOMINAL DATA UNIT INTERVAL

T_C = NOMINAL TIMING INTERVAL

T_F = FALL TIME

T_R = RISE TIME

FIGURE A-12. DATA/TIMING PHASE RELATIONSHIPS

3.1.4.4.2 PULSE EVENT SIGNAL

This is a signal actuated by an event such as a bit error and is in the form of pulses as each event occurs. Additional details are to be determined.

3.1.4.4.3 CONTINUOUS DC VARYING LEVEL SIGNAL

This is an analog signal whose instantaneous voltage amplitude is proportional to the parameter of interest (e.g. AGC voltage). (Specific details of bandwidth, impedance and voltage range will be added later).

3.1.4.5 POWER

All equipment except tropo radio sets shall operate from a station battery of -48 volts dc, with an allowable range of -44 volts dc to -56 volts dc with any variation thereof, the ripple and noise as high as 100 mV (peak-to-peak). All tropo radio sets shall operate from a power source of 117/230 volts ac +/- 10 percent single phase with a frequency of 47 Hz to 420 Hz. (Low power tropo radio set requirements may operate from the specified station battery).

3.1.5 ANTICIPATED DEPLOYMENT

The system shall be suitable for deployment in friendly and/or controlled areas and areas beyond the range of hostile land-based jammers. All parts of the system except antennas and waveguide shall be suitable for installation inside buildings in environments suitable for manned activities. Waveguides and antennas shall be selected to be suitable for the actual anticipated exterior environment at each specific site. All equipments except antennas and waveguide shall be packaged and installed is such a way as to allow removal and evacuation by the normal operation and maintenance personnel within a period not to exceed (to be determined) days.

3.2 CHARACTERISTICS

3.2.1 SYSTEM PERFORMANCE CHARACTERISTICS

The digital transmission system is composed of interconnected transmission links consisting of radio sets and various levels of multiplex. The basic transmission element is an individual RF link. One or more RF links are connected in tandem between Level 2 TDM multiplexers to form a path for digroups. One or more digroups are connected in tandem between Level 1 PCM multiplexers to form channels (voice or data). An end-to-end circuit such as the DCS circuit is composed of several global reference individual channels connected in tandem. The required value for

some system parameters such as availability or mean-time-to-loss of BCI is dependent upon a specific system configuration. For example, the availability of a channel is dependent upon the number of RF links and the number of Level 2 TDM multiplexers the channel traverses. It is thus desirable, for specification purposes, to define a standard reference configuration for which performance is specified. When different configurations are encountered in the actual system, their performance will be determined by extrapolation from the standard reference configuration specified herein.

A reference digroup is defined as two Level 2 TDM multiplexers with associated bulk encryption equipment connected by three tandem RF links (three LOS links for a Type A reference digroup or two LOS links and one tropo link for a Type B reference digroup). This configuration is shown in Figure A-13. A reference channel (voice or data) is defined as two Level 1 PCM multiplexers connected by four tandem Type A reference digroups and one Type B reference digroup. This configuration is shown in Figure A-14. The overall DCS end-to-end global reference circuit into which these elements fit and from which specific requirements are derived is described in detail in TR 12-76, Section II, 1.

System performance requirements will be specified herein for actual RF links and for each of the two standard reference configurations described above.

3.2.1.1 LOS RF LINK PERFORMANCE

Performance characteristics of the LOS RF link shall be as specified in 3.2.1.1.1 through 3.2.1.1.7. Performance characteristics are measured from either one of the two mission bit stream inputs of the transmitter to the corresponding mission bit stream output of the receiver.

3.2.1.1.1 RF LINK MARGIN

The fundamental LOS RF link performance measure is the probability of fade outages of duration greater than five seconds (see TR 12-76, sections IV,2,a, and IV,3,a). A fade outage is defined as the event that begins when the highest received signal level on any diversity branch of an RF link falls below the received signal level corresponding to a 10^{-4} bit error probability and that ends when any of these signals has again risen through that value. The probability of fade outages longer than five seconds per call-minute on the LOS RF link shall be not greater than 1.25×10^{-5}. The fade margin required to achieve this level of performance can be determined using the method of TR 12-76, section IV,3,d. Fade margin is defined as the difference in dB between the non-faded received signal level and the received signal level required to obtain a 10^{-4} bit error rate at the receiver output. RF link margin is defined as fade margin

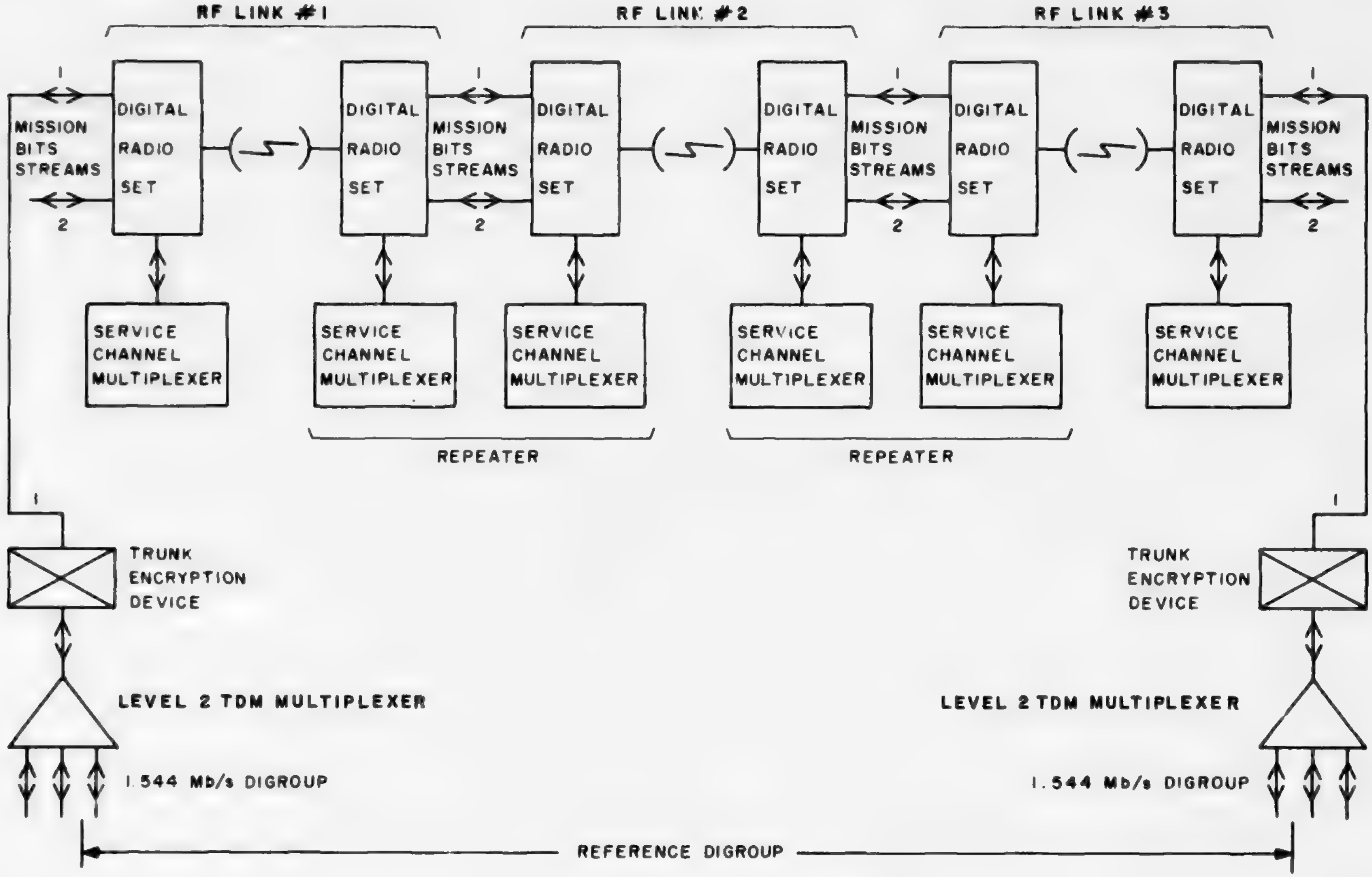


FIGURE A-13 REFERENCE DIGROUP

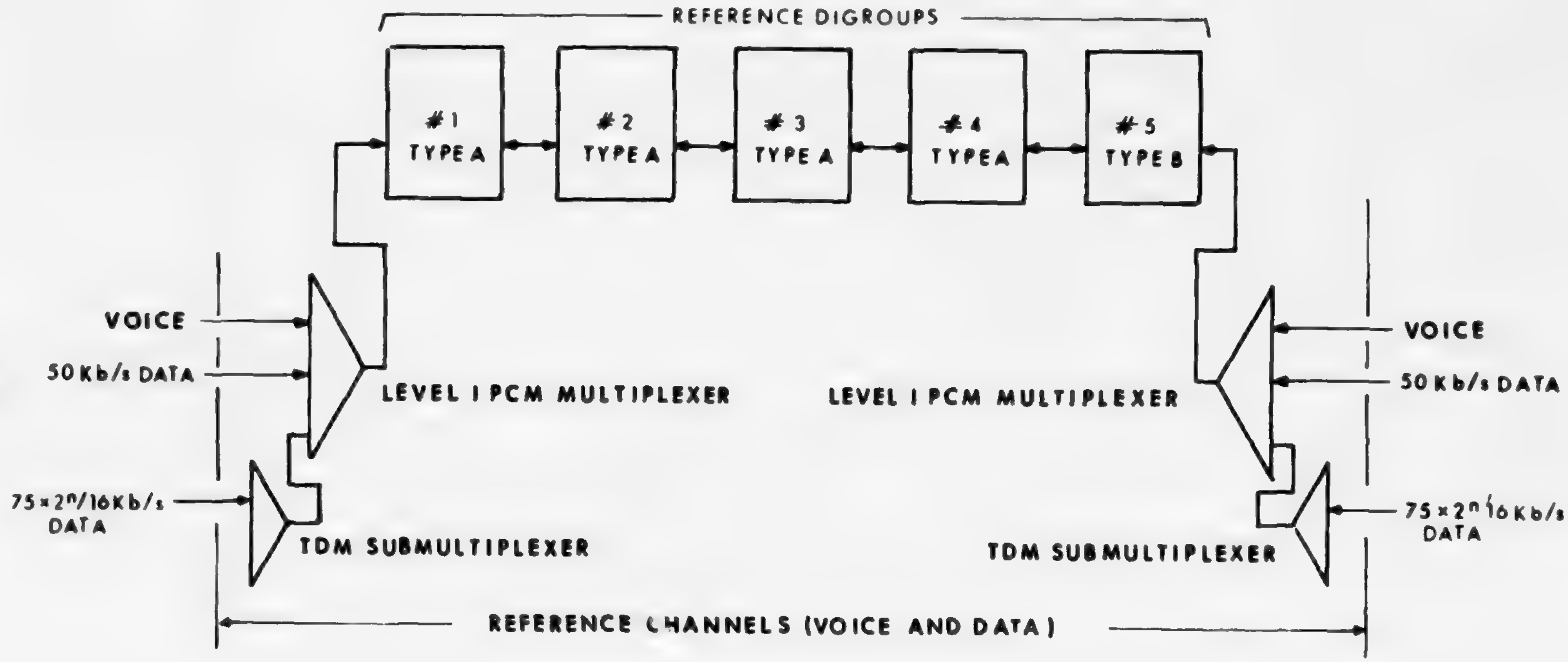


FIGURE A-14 REFERENCE CHANNELS (VOICE AND DATA)

plus a miscellaneous loss margin of 5 dB (to account for interference effects, installation losses and equipment, waveguide and antenna aging effects). For a nominal average RF link with a path length of 30 miles, an antenna diversity separation of 30 feet and average terrain and climate, the fade margin and RF link margin required to meet the above requirement for probability of fade outages are 32 dB and 37 dB, respectively. For longer paths, lower diversity separation or worse terrain, the required margins are greater and vice versa. Actual required RF link margins shall be calculated in accordance with TR 12-76, section IV,3,d.

3.2.1.1.2 SYSTEM GAIN

The system gain of the LOS RF link shall be at least 104 dB. System gain is defined as the difference between transmitter RF power output and required receiver input to obtain a 10 bit error rate where transmitter output and receiver input are measured at the equipment/waveguide interface.

3.2.1.1.3 AVAILABILITY

Availability is the cumulative percentage of time that the system is not in an outage condition where an outage is defined as any one of the following:

a) loss of path continuity for a period in excess of one minute.

b) error rate on either mission bit stream in excess of 10^{-6} for a period in excess of one minute.

c) fade outage rate in excess of five per minute for a period in excess of one minute.

The availability of the line-of-sight RF link shall be at least 0.99996.

3.2.1.1.4 BIT COUNT INTEGRITY

Not more than 2% of all fade outages on the LOS RF link shall result in a loss of bit count integrity.

3.2.1.1.5 FRAME SYNCHRONIZATION ACQUISITION TIME

The receiver internal multiplexing function shall achieve frame synchronization in not more than 50 milliseconds 95% of the time following the restoral of the transmission path to an error rate at least as low as 10^{-3}.

3.2.1.1.6 MEAN TIME TO LOSS OF SYNCHRONIZATION

The reference RF link shall experience no loss of synchronization for any condition in which BCI is maintained. Not more than 5%

of all fade outages on the LOS RF link shall result in a declaration of out-of-sync unless a loss of BCI has occurred.

3.2.1.1.7 RF BANDWIDTH

The radiated signal of the reference LOS RF link, including all RF frequency uncertainties, shall contain no energy in any 4 KHz band outside the authorized bandwidth specified in 3.1.1.3.7.1 in excess of 50 dB below the desired signal or that specified by the following relationship, whichever is lower:

$P = Po - 35 - 80((f-fo)/B) - 10 \log B$
P = power in any 4 kHz band in dBm
Po = mean power output in dBm
f = center frequency of the 4 kHz band in MHz
fo= center frequency of the authorized band in MHz
B = authorized bandwidth in MHz

No requirement exists to restrict emission to more than 80 dB below Po.

3.2.1.2 TROPO RF LINK PERFORMANCE

Performance characteristics of the troposcatter RF link shall be as specified in 3.2.1.2.1 through 3.2.1.2.6. Performance characteristics are measured from either one of the two mission bit stream inputs of the transmitter to the corresponding mission bit stream output of the receiver.

3.2.1.2.1 RF LINK MARGIN

The probability of fade outage longer than 200 milliseconds but shorter than 5 seconds per call-minute for the troposcatter RF link shall not exceed 7.5×10^{-4}. The probability of fade outage longer than 5 seconds per call minute for the troposcatter RF link shall not exceed 7.5×10^{-5}. The probability of recurrent outage rate greater than 2 per minute for the troposcatter RF link shall not exceed 2.5×10^{-3}. The RF link margin (expressed in terms of a short term signal- to-noise ratio which must be exceeded all but the above percentages of the time to meet the specified fade outage requirements) may be estimated using the methods of TR 12-76, IV,3,g.

3.2.1.2.2 AVAILABILITY

Availability and outage are as defined in 3.2.1.1.3. The availability of the troposcatter RF link shall be at least 0.99985.

3.2.1.2.3 BIT COUNT INTEGRITY

Not more than 0.1% of all fade outages on the troposcatter RF hop shall result in a loss of bit count integrity.

3.2.1.2.4 FRAME SYNCHRONIZATION ACQUISITION TIME

At a received signal level corresponding to a bit error rate of 10 the receiver internal multiplexing function shall achieve frame sysnchronization in not more than 50 milliseconds 95% of the time.

3.2.1.2.5 MEAN TIME TO LOSS OF SYNCHRONIZATION

The tropo RF link shall experience no loss of synchronization for any condition in which BCI is maintained. Not more than 0.5% of all fade outages on the tropo RF link shall result in a declaration of out-of-sync unless a loss of BCI has occurred.

3.2.1.2.6 RF BANDWIDTH

The radiated signal of the tropo RF link, including all RF frequency uncertainties, shall have 99% of its energy contained within the authorized bandwidth specified in 3.1.1.3.7.2.

3.2.1.3 TYPE A REFERENCE DIGROUP PERFORMANCE

Performance characteristics of the type A reference digroup (three LOS RF links in tandem) measured from one 1.544 Mb/s input port to the corresponding 1.544 Mb/s output port at the opposite end of the link shall be as specified in 3.2.1.3.1 through 3.2.1.3.7.

3.2.1.3.1 AVAILABILITY

Availability and outage are as defined in 3.2.1.1.3. The availability of the type A reference digroup shall be at least 0.9998.

3.2.1.3.2 BIT COUNT INTEGRITY

Not more than 10% of all fade outages on the type A reference digroup shall result in a loss of bit count integrity.

3.2.1.3.3 FRAME SYNCHRONIZATION ACQUISITION TIME

The mean time to reacquire frame synchronization following a loss of frame synchronization of the type A reference digroup shall be not greater than 50 milliseconds following restoral of all RF paths within the reference digroup to receiver input level corresponding to 10^{-3} or lower bit error rate.

3.2.1.3.4 MEAN TIME TO LOSS OF SYNCHRONIZATION

Not more than 5% of all fade outages on the type A reference digroup shall result in a declaration of out-of-sync unless a loss of PCI has occurred.

3.2.1.3.5 OUTPUT PHASE SLEWING

Phase slewing is defined as a cumulative change in relative phase between the digroup output clock signal and a phase stable reference signal at the average output clock frequency. Final values for this parameter are under study. The interim values are: The maximum variation in phase between the digroup output clock signal and a phase stable reference at the average output clock rate shall not exceed one radian over any 800 bit interval nor 0.1 radian over any 80 bit interval. This specification shall also be met with up to five Type A reference digroups connected in tandem.

3.2.1.3.6 ERROR FREE DATA BLOCKS

Not more than 0.0125 percent of all 1000 bit blocks of data transmitted via the type A reference digroup during periods having no equipment failure outages shall contain errors. All other data blocks transmitted during such periods shall be error free.

3.2.1.3.7 PROBABILITY OF FADE OUTAGE

The probability of fade outages longer than five seconds per call-minute on the type A reference digroup shall be no greater than 3.75×10^{-5}. A fade outage is as defined in 3.2.1.1.1.

3.2.1.4 TYPE B REFERENCE DIGROUP PERFORMANCE

Performance characteristics of the type B reference digroup (two LOS RF links and one tropo RF link in tandem) measured from one 1.544 Mb/s input port to the corresponding 1.544 Mb/s output port at the opposite end of the link shall be as specified in 3.2.1.4.1 through 3.2.1.4.7.

3.2.1.4.1 AVAILABILITY

Availability and outage are as defined in 3.2.1.1.3. The unavailability of the type B reference digroup shall be at least 0.9997.

3.2.1.4.2 BIT COUNT INTEGRITY

Not more than 2% of all fade outages on the type B reference digroup shall result in a loss of bit count integrity.

3.2.1.4.3 FRAME SYNCHRONIZATION ACQUISITION TIME

The mean time to reacquire frame synchronization following a loss of frame synchronization on the type B reference digroup transmission link shall be not greater than 50 milliseconds following restoral of all RF paths within the reference digroup to receiver input level corresponding to a 10^{-3} or lower bit error rate.

3.2.1.4.4 MEAN TIME TO LOSS OF SYNCHRONIZATION

Not more than 1% of all fade outages on the type B reference digroup shall result in a declaration of out-of-sync unless a loss of BCI has occurred.

3.2.1.4.5 OUTPUT PHASE SLEWING

Phase slewing is defined as a cumulative change in relative phase between the digroup output clock signal and a phase stable reference signal at the average output clock frequency. Final values for this parameter are under study. The interim values are: The maximum variation in phase between the digroup output clock signal and a stable phase reference at the average output clock rate shall not exceed one radian over any 800 bit interval nor 0.1 radian over any 80 bit interval. This specification shall also be met with up to five Type B reference digroups connected in tandem.

3.2.1.4.6 ERROR FREE DATA BLOCKS

Not more than 0.025 percent of all 1000 bit blocks of data transmitted via the type B reference digroup during periods having no equipment failure outages shall contain errors. All other data blocks transmitted during such periods shall be error free.

3.2.1.4.7 PROBABILITY OF FADE OUTAGE

The probability of fade outages longer than five seconds per call-minute on the type B reference digroup shall be no greater than 10^{-4}. A fade outage is as defined in 3.2.1.1.1.

3.2.1.5 REFERENCE VOICE CHANNEL PERFORMANCE

Performance characteristics of the reference voice channel as defined in 3.2.1 and depicted in Figure A-14 shall be as specified in 3.2.1.5.1 through 3.2.1.5.2. Performance characteristics for the reference voice channel shall be measured from the voice channel input of one Level 1 PCM multiplexer to the corresponding voice channel output of a Level 1 PCM multiplexer at the opposite end of the channel.

3.2.1.5.1 AVAILABILITY

Availability is the cumulative percentage of time that the system is not in an outage condition. An outage for the reference voice channel is defined as any period in excess of one minute in which the bit error rate measured at the 1.544 Mb/s input to the channel demultiplexer is greater than 10^{-6} or any period in excess of one minute in which channel performance as specified in 3.2.1.5.2 is not maintained (e.g., channel quality degradation due to Level 1 PCM multiplexer component failures). The availability of the reference voice channel shall be at least 0.999.

3.2.1.5.2 VOICE CHANNEL CHARACTERISTICS

The detailed transfer characteristics and non-faded distortion/noise characteristics of the reference voice channel shall be as specified in specification CCC-74047, Specification for Multiplexer/Demultiplexer TD-1192( ) P/F, paragraph 3.2. In general, the VF channel characteristics are those of 64 kb/s, -law companded pulse code modulation with nominal 300-3400 Hz bandwidth and providing built-in E&M-lead supervisory signalling.

3.2.1.6 REFERENCE DATA CHANNEL PERFORMANCE 16000x2^N B/S AND 50 KB/S

Performance characteristics of the reference data channel (as defined in 3.2.1 and depcited in Figure 14) shall be as specified in 3.2.1.6.1 through 3.2.1.6.4. Performance characteristics of the reference data channel shall be as measured from the data submultiplexer channel input to the corresponding channel output of the data submultiplexer at the opposite end of the channel for 16000x2^N b/s data channels (N=0,1,2,3), and shall be from the channel input of the Level 1 PCM multiplexer to the corresponding channel output of the Level 1 PCM demultiplexer at the opposite end of the channel for 50 kb/s data channels.

3.2.1.6.1 AVAILABILITY

An outage for the reference data channel is defined as any period in excess of one minute in which the bit error rate at the channel output exceeds 10^{-6}. The availability of the reference data channel shall be at least 0.999.

3.2.1.6.2 BIT COUNT INTEGRITY

Not more than 5% of all fade outages on the reference data channel shall result in a loss of bit count integrity.

3.2.1.6.3 PHASE SLEWING

Phase slewing is defined as a cumulative change in relative phase

between the data channel output clock signal and a phase stable reference signal at the average output clock signal. Phase slewing on the output of the reference data channel in asynchronous mode shall not exceed a peak relative phase excursion of one radian over any 3200 bit interval nor 0.1 radians over any 320 bit interval. The phase slewing requirements for synchronous mode are (to be determined).

3.2.1.6.4 ERROR FREE DATA BLOCKS

Not more than 0.06 percent of all 1000 bits blocks of data transmission via the reference data channel during periods having no equipment failure outages shall contain errors. All other data blocks transmitted during such periods shall be error free.

3.2.1.7 REFERENCE WIDEBAND DATA CHANNEL

The reference wideband data channel shall operate at a data rate of 1.544, 3.088 or 6.176 Mb/s and shall be composed of appropriately strapped ports of the reference digroup transmission link. The performance of the reference wideband data channel shall be the same as that of the reference digroup.

3.2.1.8 REFERENCE LOW SPEED DATA CHANNEL

(To be determined--specified parameters will include availability, mean time to loss of BCI and character error rate.)

3.2.1.9 SERVICE CHANNEL CHARACTERISTICS

3.2.1.9.1 GENERAL

The system shall provide two voice service channels plus one data channel that are separate from and independent of the mission channels. These service channels shall have appearances at every site of the system.

3.2.1.9.2 VOICE SERVICE CHANNEL NETWORKS

The system shall provide suitable bridging and/or switching capability to allow the configuration of service channels into networks of up to 100 individual sites. A suitable method of signalling between sites shall be provided to allow personnel at any site of a network to gain the attention of personnel at any other site of the network. The actual size of each service channel network and the number of such networks within the system will be determined by system deployment. The service channel equipment within the system shall not limit achievable network configurations except as specified herein.

3.2.1.9.3 DATA SERVICE CHANNEL NETWORKS

The data service channel shall be capable of forming networks of interconnected sites in which each site can insert data in an appropriate preprogrammed way. Each site shall be provided with at least 600 bit/second data insertion capability. The data channel shall provide at least 32 kb/s capacity.

3.2.1.9.4 VOICE CHANNEL CHARACTERISTICS

Service channel voice channels between any two adjacent sites shall meet the requirements of 3.2.1.5.2. The unavailability of service channel voice channels between any two adjacent sites shall not exceed 2×10^{-4}.

3.2.1.9.5 DATA CHANNEL CHARACTERISTICS

Service channel data channels between any two adjacent nodes shall meet the requirements of 3.2.1.6 with the following exceptions: (to be determined)

3.2.1.10 FAULT ALARM AND MONITORING CHARACTERISTICS

3.2.1.10.1 ALARMS AND STATUS INDICATIONS

The system shall provide output alarms and status indications to indicate selected equipment failures/status as specified in individual equipment specifications and to the extent necessary to meet equipment failure related availability requirements specified herein. These alarms shall automatically detect and automatically isolate at least 75% of all failures affecting two or more VF channels to a specific equipment and at least 97% of all failures affecting two or more VF channels to a specific site. The system shall provide alarm indications for failure of redundant units sufficient to allow repair of these failures as needed to meet availability requirements specified herein. Whenever switched redundancy or switched functional bypass is used, the system shall provide a status output indicating which of the switching units is the on-line unit. The system shall provide an alarm indication whenever a synchronized unit of equipment loses synchronization.

3.2.1.10.2 PERFORMANCE MONITORING

Equipments within the system shall provide the following performance indications as appropriate to the particular equipment:

a. Received signal level - an output indication capable of describing the received signal level into system receivers.

b. Framing bit errors - an output indication from each unit which detects and aligns a time division framed signal that indicates the occurrence of errors in frame signals.

c. Received signal quality - an output indication capable of describing the predetection signal-to-noise ratio of each receiver demodulator.

3.2.1.11 ENCRYPTION CHARACTERISTICS

The system shall provide bulk encryption for all mission bit streams and have the ability to encrypt all service channel bit streams. The system shall be compatible with the TSEC/CI-3 (KG-81) encryption equipment. Mission bit streams shall be capable of being encrypted on an individual digroup basis or as a combined mission bit stream at data rates up to 14 Mb/s. Service channel bit streams shall be capable of being separately encrypted. The performance requirements specified in 3.2.1 shall be met with bulk encryption applied to all mission bit streams. The bulk encryption capability when provided at the mission bit stream level shall be provided with a clear text bypass arrangement that allows a manual or automated bypass of the encryption unit in the event of failure. Transfer into the clear text bypass mode shall be indicated by a remote alarm. Since the bulk encrypted digital transmission facilities will handle only unclassified traffic, traditional TEMPEST requirements shall not apply. Individual equipments shall meet appropriate requirements of MIL-STD-461, Electromagnètic Interference Characteristics Requirements for Equipments. Installation practices and procedures for equipments shall meet the requirements for BLACK systems of MIL-HDBK-232, MIL-HDBK for RED/BLACK Engineering Installation Guidelines. Each installation site shall be inspected and evaluated to determine whether an adequate area of U.S. control surrounding the equipment location necessitates the implementation of additional measures for protection against interception.

3.2.1.12 RF INTERFERENCE CONTROL CHARACTERISTICS

To be completed in a later issue of this specification. The requirements to be specified will include:

a. Minimum transmitter-to-receiver frequency spacing.

b. Minimum transmitter-to-transmitter frequency spacing.

c. Minimum receiver-to-receiver frequency spacing.

d. Minimum geographical separation required for frequency reuse.

e. Minimum geographical and frequency separation for adjacent channel use.

f. Receiver spurious rejection requirements.

g. Receiver intermodulation requirements.

h. Transmitter spurious output requirements.

3.2.2 PHYSICAL CHARACTERISTICS - to be determined in a later issue is applicable.

3.2.3 RELIABILITY

The reliability of the system shall be sufficient to meet availability requirements specified in applicable portions of 3.2.1.

3.2.4 MAINTENANCE/RESTORABILITY

The mean time to restore system failures which result in a system service outage shall not exceed 30 minutes for manned stations and 3 hours for unmanned stations. The time to restore shall include all time from the occurence of the failure until restoral of service. The system shall be capable of being remotely looped back or of remotely switching redundant units at key points at each unattended location to facilitate fault isolation.

3.2.4.1 CONTROLS AND ADJUSTMENTS

The system shall be designed with the minimum practical number of manual field controls and adjustments. The stability of system equipment alignment shall be such that no adjustment is required to meet all requirements of this specification for a continuous 30 day period.

3.2.5 ENVIRONMENTAL REQUIREMENTS

All system equipments except antennas and exterior waveguides shall operate continuously and shall meet all performance requirements of this specification when subjected to any combination of temperature, altitude and humidity in the following ranges:

temperature	0 Deg. C to 50 Deg. C
relative humidity	0% to 95%
altitude	0 to 15,000 feet msl

Antennas and waveguide components shall be selected to be suitable for the actual anticipated exterior environment at each specific site.

3.2.6 ELECTRONIC COUNTER COUNTER MEASURES (ECCM)

A potential jamming threat to the DCS exists due to known capabilities of potential enemies (Draft Final Report-- European Command, Control and Communications Study Group, 25 April 1975, Appendix C--"Threat to Europe C-3," Annex D--"Warsaw Pact ECM.") The cost-effectiveness of applying specific ECCM measures to the system versus seeking alternative ways to assure critical command and control communications is under study. Results of this study will be added to this specification, if appropriate, at a later

issue.

3.2.7 NUCLEAR ENVIRONMENT

The digital transmission system shall be protected against permanent damage due to the effects of a high altitude electromagnetic pulse. All external transmission lines entering a facility shall be protected with suitable surge arrestors. Provisions for the protection of equipment and cabling internal to a station shall be determined by studies not yet complete and will be furnished in a later issue.

3.3 DESIGN AND CONSTRUCTION

3.3.1 PARTS, MATERIALS, AND PROCESSES

The selection and application of parts, materials, and processes for and during fabrication of the equipment shall be suitable to meet requirements specified herein for reliability, environmental and EMI.

3.3.2 IDENTIFICATION AND MARKING

All markings shall be clear, concise, legible, and permanent. The system equipment assemblies, and modules shall be marked with identification as delineated below.

3.3.2.1 CONTROLS

All controls shall be clearly marked in a manner which indicates their function and enhances the ability to adjust the system equipment.

3.3.2.2. COMPONENTS AND MODULES

All lamps, switches, fuses, jacks, and test points shall be marked. All other components referenced in the schematic diagrams shall be marked wherever possible.

3.3.2.3 WIRING

All terminal strips shall have each terminal numbered and all wires leading thereto shall be identified with permanent numbered sleeves or equivalent. Each cable and receptable shall be marked with a permanent cable band or stencil, respectively, giving reference designators.

3.3.2.4 DIAGRAMS AND CHARTS

Decals and captive plastic encased diagrams and charts shall be provided in appropriate places on or adjacent to cards, modules, or chassis to depict the following:

a. Alignment procedures.
b. Normal levels for all test points and meter readings.

3.3.3 WORKMANSHIP

Workmanship shall be in accordance with MIL-STD-454, requirement 9.

3.3.3.1 FACTORY ADJUSTMENT

Controls which do not require adjustment during routine maintainance and operation shall be sealed at the factory with glyptol or equivalent.

3.3.4 INTERCHANGEABILITY

Provisions for interchangeabilty shall be in accordance with MIL-STD-454, Requirement 7.

3.3.4.1 MODULARITY AND COMMONALITY

Modular construction shall be employed and the equipment shall be designed for fixed-plant installation. The equipment shall be designed with replaceable plug-in modules and plug-in printed circuit cards. Printed circuit boards used within replaceable plug-in modules are not required to be plug-in. Plug-in modules and cards shall be designed to permit maximum interchangeability. All plug-in modules and cards shall be keyed to prevent errors in replacement. All replaceable components shall be limited to as few different types as possible to simplify spare parts stocking requirements. All plug-in modules and cards shall be provided with test points and shall require no unsoldering or removal of wires in order to remove the modules or cards. Pin jacks may be used for front panel test points. Modules and cards shall be securely locked in position when in place so that they cannot be loosened by vibration. This requirement may be met by a mechanical detent device. Friction alone is not adequate.

3.3.5 SAFETY

All construction and material installation shall be designed to prevent injury to personnel or equipment during installation, operation, and maintenance. Personnel safety provisions shall conform to MIL-STD-454, Requirement 1.

3.4 DOCUMENTATION - TBD

3.5 LOGISTICS - TBD

3.6 DETAILED FUNCTIONAL EQUIPMENT CHARACTERISTICS

(To be determined) designation below reflects that detailed

equipment specifications for each unit will be referenced when they are completed. Plans for these equipments are contained in the DCA RDT&E Plan.)

3.6.1 LEVEL 1 PCM MULTIPLEXER - CCC-74047

3.6.2 LEVEL 2 TDM MULTIPLEXER - CCC-74048

3.6.3 LEVEL A $16000x2^N$ TDM SUBMULTIPLEXER - TBD

3.6.4 LEVEL B LOW/MEDIUM SPEED TDM SUBMULTIPLEXER - TBD

3.6.5 SERVICE CHANNEL MULTIPLEXER - TBD

3.6.6 LOS DIGITAL RADIO SET - CCC-74049

3.6.7 DIGITAL APPLIQUE UNIT - TBD

3.6.8 TROPO DIGITAL RADIO SET - TBD

3.6.9 STATION CLOCK AND TIMING SUBSYSTEM - TBD

3.6.10 TRANSMISSION STATUS MONITORING AND CONTROL UNIT - TBD

3.6.11 BULK ENCRYPTION UNIT - TT-B1-6002-0009

4.0 SYSTEM TEST REQUIREMENTS - TBD

APPENDIX B

PROBABILISTIC BASIS FOR FADE OUTAGE, AVAILABILITY AND ERROR FREE BLOCK CRITERIA

In a number of areas in this report, a parameter used to describe the performance of a composite circuit, composed of a large number of component elements, is represented to be equal to the sum of the value of the parameter for each of the component elements. For example, the unavailability (one minus the availability) of a circuit is said to be equal to the sum of the unavailabilities of each segment of the circuit. Strictly speaking, this representation is an approximation but it is an approximation that is sufficiently valid as used herein. This appendix is provided as a generalized explanation of this approximation to avoid continuing explanations throughout the report. The necessary condition for the validity of this approximation are:

a. The composite parameter is the complement of the probability of occurrence of some event or condition on the composite channel.

b. The individual component parameters are the complements of the probability of occurrence of the event or condition in the component elements.

c. The component element probabilities are independent.

d. The component element complements are very much less than unity.

Examples of parameters which are included in the above category are unavailability, probability of fade outage and error-free-block probability. Of the above conditions, a. and b. apply to these parameters by definition. Condition d. applies to all of them by design since the design goal for each of these characteristics at the composite level is itself very much less than unity, hence rendering each of the N components even smaller.

Condition c. above, that of independence is less obviously valid for all cases. For all propagation related phenomena, the assumption of statistical independence among a tandem set of RF links is not true to the extent that the per link probability of occurrence is seasonally or diurnally related. Such is the case for all of the specified line-of-sight propagation phenomena. (For troposcatter links this seasonal and diurnal correlation was assumed.) The parameter is additive as assumed herein about these LOS propagation mean value. Thus, the composite value represented herein for a parameter such as fade outage

probability is actually the annual mean value of this parameter. During the fading season, all RF links which are geographically within that season will have a fade probability greater than the mean and thus the composite probability during that season will be considerably higher than the mean. Conversely during the non-fading season, the composite probability will be considerably lower than the mean. The allocation of requirements herein, based on annual averages, is an engineering judgment that it is not desirable to engineer for an overall worst case condition which includes both a worst case connection (i.e., the global reference circuit) and a worst case hour of the year. It is expected that the short term value of the composite parameter will very rarely exceed its mean by more than an order of magnitude, and will generally reside even nearer to the mean.

APPENDIX C

COMPARISON OF LINE-OF-SIGHT LINK DESIGN CRITERIA

The following is a comparison of the RF link margin requirements for a typical DCS line-of-sight link based on the fade outage probability criterion specified herein vice the previously used media availability criterion.

Consider the design of an RF link of 30 mile (48 km) length with dual space diversity reception, 30 foot (9.1 meter) antenna separation, traversing average terrain and climate.

The previous design criterion was a 0.99999 media availability to a bit-error-rate threshold of 5×10^{-9}. The media unavailability for this link is obtained from section IV,3,d, equation (1). This equation has been evaluated for the case in question and is plotted in Figure 3. The fade margin required for the specified availability, from Figure 3 is 30 dB. This means that the engineered median, non-faded value for received signal level (RSL) must be 30 dB above the RSL which corresponds to a 5×10^{-9} bit-error-rate for the selected RF receiver. No additional miscellaneous loss margin (Lm of section IV,3,E, equation 8) was specified in the previous design criterion.

The present design criterion is a 1.25×10^{-5} probability of fade outage in outage range III where a fade outage is any period of sufficient duration in which the RSL is below that corresponding to a 10^{-4} bit-error-rate. From section IV,3,d, Figure 6, the fade margin required to meet this criterion is 32 dB. In the present link design approach, an additional 6 dB margin is required for miscellaneous losses. This means that the engineered median, non-faded value for RSL must be 38 dB above that which corresponds to a 10^{-4} bit-error-rate. Since there is a difference of approximately 3.7 dB between the 10^{-4} bit-error-rate point and the 5×10^{-9} bit-error-rate point for a typical LOS receiver, the above link design criterion can be restated as the non-faded RSL value must be 34.3 dB above the 5×10^{-9} bit-error-rate point. Thus, the link design specified herein requires 4.3 dB more link margin than does the previously used criterion.

APPENDIX D

QUALITY ASSURANCE TEST METHODS FOR DCS LOS LINKS

1. INTRODUCTION

This appendix discusses methods to assess whether installed DCS links meet the link performance requirements specified herein. Such an assessment is necessary for system acceptance testing and for periodic quality assurance testing. Some of the characteristics of the system, such as the specified VF channel characteristics, are relatively straightforward to test and are not discussed here. The basic link design requirements, however, such as fade outage probability and availability, are probabilistic in nature and thus their test verification is not straightforward. This appendix discusses recommended testing of DCS LOS links to verify that the probalistic link design requirements such as outage probability and availability are being met. Thus, it is not intended that this appendix be considered an exhaustive treatment of all necessary LOS link testing. Similar testing requirements for verifying probablistic requirements of troposcatter links are more complex and are treated separately in TR 17-76.

Since a single link represents a very small portion of the total overall circuit, its performance must be extremely good in order that the combined performance of all links provides acceptable quality for the overall circuit. Thus, the specified requirements for probability of fade outage and mean-time-between-equipment-outage, when applied to an individual link, have values so small that their verification would require a prohibitively expensive test. For example, a typical requirement for the mean-time-between-fade-outage on a 30-mile diversity RF link is 3×10^6 seconds or about 35 days. In order to obtain an adequate test of this parameter, the test period would need to be on the order of ten times the mean or nearly a year. Similarly, the mean-time-between-equipment-outages for an unattended repeater is approximately 55,000 hours or 6-1/3 years. Clearly, the above parameters are not suitable for direct measurement. Thus, acceptance testing and quality assurance testing of DCS links should be aimed at verifying intermediate level characteristics of the installed links which are related to the above system-level requirements in a known way, rather than attempting to directly test the primary, system-level requirements.

2. BASIC INTEGRATION TESTING

Prior to testing that is aimed at verifying that installed links meet statistical system criteria, it is desirable to verify that the normal, non-faded and non-failed operation of the system is acceptable. Thus, link and channel tests should be performed

(down to the lowest level of multiplexing in the installation) during a period with low probability of deep fading, such as the hours around local midday (11:00 a.m. - 3:00 p.m.). During this period, the received signal level should be monitored to verify that no fading of more than a few dB is occurring. With no or moderate fading, the portion of the system under test should be essentially error-free. Any significant amount of errors during these conditions must be considered as representing either a faulty unit of equipment or an installation difficulty and should be corrected. During this test, not only should the error free state be verified but also the receiver signal quality monitor (SQM) indication should be compatible with previously obtained factory test data relating the SQM value to a value of RSL equivalent to that being received. VF channel characteristics should also be equivalent to the PCM multiplexer back-to-back specifications. An additional test that should be performed on the installed system is to measure the signal-to-noise margin of digital lines between equipments. The sources of perturbation in these interfaces are excessive noise pickup variation in ground potential between equipments, inadequate circuit balance and pulse shape distortion due to cabling irregularities. Testing of this interface must be performed very carefully to assure that the test instrumentation does not introduce more perturbation than the effect to be tested.

3. BIT ERROR RATE TESTING

Since the systems under discussion are digital systems, it would at first appear that a bit error rate test would be fundamental to all other testing. This is so but not in the normally expected manner. A properly installed system composed of digital radio relay links should exhibit a bit error rate, in the absence of fading or EMI, which is too small to be tested. Thus, a test of the system for errors, under normal, non-faded conditions should be performed but since essentially no errors should be observed, this test can not truly be termed a bit error rate test. Bit errors do occur in a digital system during RF fading but under these conditions, the error performance varies too rapidly to be characterized by an error rate. Appropriate testing of the system fade margin is discussed in the following paragraph.

4. LINK QUALITY TESTING

The basic link quality parameters are the probability of fade outage, the mean-time-between-fade-outages and propagation "unavailability", all of which are related to each other and all of which are functions of the following variables:

F = link fade margin in dB
D = link length in statute miles
S = space diversity antenna separation in feet
a = percentage of the year constituting the fading season

c = climate the terrain roughness factor for subject link
$r2$ = receiver diversity switching hysteresis ratio

These parameters are related to basic link performance by equations such as eq. (1) of TR 12-76, para. IV, 3, d which express space diversity link propagation "unavailability" as

$$P_o = (r^2 + \frac{1}{r^2}) \frac{acD^4}{56\ s^2} 10^{-0.2F}$$

Of the above parameters, r is a directly measureable characteristics of the RF receiver and both S and D are easily determined characteristics of the path. Thus, the real unknowns which might be verified during link testing are F, a and c. It is theoretically possible to verify the value of a and c for each installed link but this is realistically impractical since several years of testing would be needed to truly verify the actual values of a and c while their potential variability is not large enough to justify the effort. Thus, link testing resolves itself to verification that the intended fade margin is actually achieved and that the link is free from unpredictable installation deficiencies.

To test link fade margin several steps are required. First, the expected unfaded RSL should be calculated. Next the receiver RSL indicator should be calibrated to verify the RSL indication corresponding to the expected unfaded RSL. The actual RSL should be recorded for several days. Although periods of considerable fading may occur during this sample period, significant periods of time should be observed during which the RSL is essentially constant and unfaded. These periods of stable RSL should be located within the sample period. They should be very nearly the same from day to day and represent the non-faded RSL for the link. Following these tests, the RSL monitor should be observed to locate another such period of stable, non-faded RSL. Such periods would normally be expected to occur around local midday (11:00 a.m. to 3:00 p.m.). A calibrated attenuator should be inserted at the receiver input and attenuation should be increased until the receiver output bit error rate is approximately 10^{-4}. During this test period, the RSL should be monitored to assure that the attenuated RSL remains equal to the previously determined non-faded RSL minus the attenuator loss (i.e., that the RSL prior to the attenuator stays constant at the non-faded link RSL value). The amount of attenuation that has been added is equal to the actual realized non-diversity link margin. This test should be conducted separately on each diversity receiver with the diversity combines disabled. Then a difference in the attenuator values on both diversity branches, equal to the diversity hysteresis ratio, should be introduced with the diversity switch operative to verify diversity switch performance. Finally,

additional RF attenuation should be added until the bit error rate at the receiver output is in the range of 10^{-1} to 10^{-2}. At this level, the number of losses of bit count integrity and loss of frame synchronization should be counted over a controlled time period. During this period, the RSL must be monitored to verify that it remains stable. Any variation in RSL during the test period greater than about ± 1 dB should be cause for retesting. The specific bit error rate and test time interval must be determined from as-yet-unknown characteristics of the Level 1 and Level 2 multiplexers.

If the link fade margin is confirmed to be approximately equal to the intended design value by testing as described above, then the link can be considered to have achieved its intended design. If subsequent to installation, a particular link appears to provide substandard propagation "availability", an extended test could be structured to investigated the possibility of inadequate siting or a persistent local atmospheric anomaly. If it falls short due to inadequate measured "non-faded" RSL, antenna orientation and waveguide losses should be investigated. If it meets ambient RSL expectation but has excessive error rate, RFI and installation noise problems should be investigated.

5. LINK AVAILABILITY

Link availability is a function of the mean-time-between-outage performance of prime equipments and station power, and of the degree of anomalous RF fading which occurs on the link. None of the above parameters is suitable for direct testing. Anomalous fading can be minimized by providing adequate path clearance. Verification of path clearance adequacy should be evaluated on marginal links by variable height antenna tests during a path testing phase of link installation. For links where path clearance is clearly more than adequate, such testing is not necessary.

Direct testing of the reliability of equipment is not a practical way of verifying mean-time-between-outage (MTBO) values as large as those required of most DCS equipments. The high MTBO values required are obtained using redundancy. Whether this redundancy actually provides the desired MTBO is primarily determined by the adequacy of automatic fault detection and switchover circuitry. A recommended means for "verifying" MTBO is to direct each basic equipment supplier to perform the following analysis and tests:

1) Perform a failure mode and effect analysis to predict the expected distribution of external failure symptoms. For example, for an RF transmitter what percentage of internal (component) failures will result in loss of power output versus loss of modulation versus change of output frequency, etc.

2) Verify that the set of performance monitor sensors implemented by the equipment contractor actually detect the failure symptom they are intended to detect. Verify that this combination of sensors should be expected to detect the necessary percentage of all failures.

3) Verify basic non-redundant equipment MTBF by analysis or test. The combination of the above should yield MTBO from the equation.

$$MTBO = \frac{\text{non-redundant MTBF}}{\text{(1-fraction of failures automatically switched)}}$$

Thus, the MTBO of DCS equipments should be verified at the equipment level by the equipment supplier.

The other basic determinant of availability besides MTBO is MTSR. MTSR is primarily determined by the provision of adequate spare parts logistics so that when a failure is found it can be immediately fixed, and provision of adequate manning so that the travel time and administrative waiting time component of restoral is held within acceptable bounds. Both of the above factors can be verified by inspection. If a portion of the system is to be maintained by MILDEP activity, the MILDEP should make adequate logistics and manning plans, preferably described by a suitable MTSR analysis. For portions of the system which are to be contractor operated and maintained (such as one procurement option for the Washington Area Wideband System), the contractor's proposal should be required to provide a definitive analysis of (1) failure rates, (2) needed logistics stocking levels which take into account resupply lead time for parts, (3) manning plans which validate that maintenance travel time will not be excessive and (4) an analysis of adequacy of alarm remoting that shows that restoral at unattended sites can be accomplished adequately by remote action or by a single maintenance trip.